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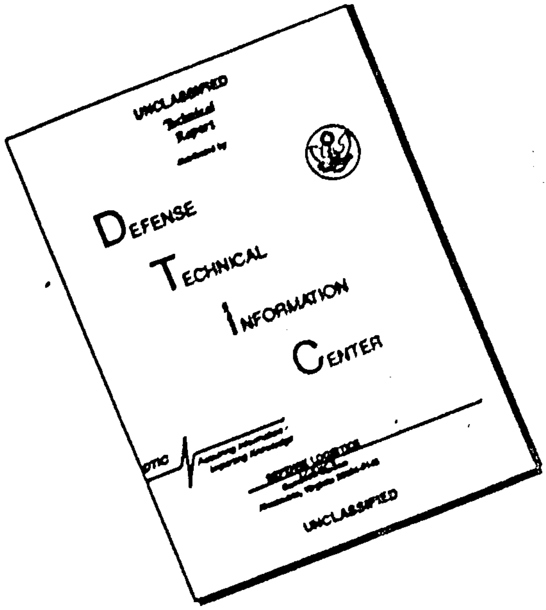

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TECHNICAL REPORT FRL-TR-41

BURNING CHARACTERISTICS OF STANDARD GUN PROPELLANTS AT LOW TEMPERATURES (21°C TO −52°C)

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NOVEMBER 1961

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DOVER, N. J.

ORDNANCE PROJECT WDOAC-4700-142-19-99105 ITEM D-2-11

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SUMMARY

The burning characteristics of M-1, M-2, M-6, M-10, M-15, M-17, T-28, T-34, and T-36 propellants were determined in a closed bomb between -52°C and +21°C. Burning rates for most of these propellants either decreased 1% to 2% per 10°C decrease in temperature or remained essentially constant throughout the temperature range. The apparent burning rate of the M-17 propellant, however, increased abruptly at -21°C. The maximum pressure developed by these propellants at -52°C averaged 7% less than the pressure developed at ambient temperature. Equations for the pressure-burning rate relationship as well as temperature coefficients of burning rate were calculated. The effect of loading density on the maximum pressure is shown to be highly significant, and its effect on burning rate is also discussed.

CONCLUSIONS

1. With the exception of the M-17 propellant, all standard propellants tested undergo small changes in burning rate at reduced temperatures.

2. Single-base propellant compositions are less temperature dependent than double-base compositions.

3. The maximum pressure of the propellants decreases approximately 7% between 21°C and -52°C.

4. Burning rates obtained from closed bomb data are not absolute because of the effect of heat loss and the undefined geometric state during the burning process. However, these values reflect similar conditions in the gun.

5. The ratio of propellant weight to bomb volume (loading density) has a marked effect on maximum pressure developed per gram, and on burning rate.

RECOMMENDATIONS

1. A study of unstable burning should be made. This should include the effects of temperature and pressure on the surface area of propellants. A study of the properties of propellant ingredients over a complete temperature range should also be included.

2. The reasons for the highly significant increases in pressures per gram of propellant which accompanied increases in loading density should also be investigated. This investigation should include a study of variations of the heat reaction with loading density and an investigation of the products of reaction. Results of such a study may prove applicable to rocket propellants for ascertaining optimum pressure conditions of operation.

3. If more exact burning rates are required, it is recommended that corrections for heat loss be made by firing a given propellant having different web sizes (burning time) and correlating the results with strand burner data.

4. Firings at 0.2 Δ should be made down to -52°C for all propellants.

5. The use of the closed bomb for propellant acceptance should be investigated. The initial step should be a compilation of data on all previous closed bomb work with the standard propellants.

INTRODUCTION

This is the third in a series of reports on the closed bomb evaluation of standard propellants at low temperatures. In the two previous reports (Refs 1 and 2) the burning characteristics of M-2, M-6, M-9, M-15, and M-17 propellants were investigated between ambient temperature and -52°C at 0.1 g/cc loading density. In this report, additional results are given for some of these propellants as well as other standard propellants to 0.2 g/cc loading density. This was made possible during the second year of the present study when teflon-bonded silicon rubber capable of withstanding pressures of 40,000 psi at -52°C was made available. Time did not allow, however, the determination of burning characteristics of all propellants at 0.2 g/cc loading density and -52°C. It is therefore recommended that this be done in order to obtain results up to the actual operating pressure of the propellant in the weapon.

Burning rate data programmed on a digital computer* are presented. The burning rate can be expressed as a function of pressure by the equation

$$r = BP^n$$

and, where applicable, as a function of temperature and pressure by the equation

$$r = BP^n e^{-K_B \Delta T}.$$

Constants for these equations are listed in Table 2 (p 9).

The original objective of this study was to obtain more extensive information on the burning characteristics of standard propellants at low temperatures. This information could then be used to characterize and evaluate other propellants of the same class. Although propellants of the same composition should exhibit equal burning rates, the experimental determination of these burning rates in the closed bomb shows a dependency on geometry. The geometry of the grain affects the burning time, which in turn results in a difference in the quantity of pressure lost to the bomb walls in the form of heat. Because no correction for heat loss is made in the calculation of burning rate, a value somewhat different from the absolute one is obtained. The rates obtained from the closed bomb, however, are not to be considered invalid because of this deficiency. The fact is that they become more useful since this condition more closely reflects the actual conditions in the gun. The information obtained in this study can, therefore, be useful in ascertaining the interior ballistics of these propellants in a gun at temperatures to -52°C.

*The method used in calculating the burning rate by digital computer will be published in the near future in another report.

RESULTS

The compositions of the standard propellants tested are given in Table 1 (p 8). A summary of the burning rate equation constants and temperature coefficients of the propellants is shown in Table 2. The temperature coefficients (K_B) are applicable from 21°C to -52°C, except where otherwise noted. Table 3 (p 10) shows the effect of loading density on maximum pressure and burning time. The effect of temperature on maximum pressure is shown in Table 4 (p 11). Table 5 (p 12) shows the effect of geometry on the burning rates and the maximum pressures of several classes of propellant. The burning rates of the standard propellants at various pressures and temperatures are listed in Tables 6 to 34 (pp 13 to 41). The burning rate data in these tables and the relationships of loading density, pressure, and burning time are shown in Figures 1 through 59 (pp 42 through 100).

DISCUSSION

Effect of Temperature on Burning Rate

It is difficult to assess the effect of temperature per se on the burning rate of a propellant. This is particularly true at low temperatures where propellant ingredients may undergo physical transitions, and where mechanical separation of the ingredients may occur. These transitions induce changes in the surface area of the propellant which have significant and unpredictable effects on the apparent burning rate of the propellant. (The term "apparent" burning rate is used because in closed bomb work the calculation of the burning rate is dependent on the original geometry of the propellant. Although the burning rate may be constant, a breakdown in the geometry of the propellant may cause apparent increases in burning rate.) It is therefore necessary, in any discussion of burning rate vs temperature, to consider the physical state of the propellant.

An examination of the figures in which the relationship between burning rate and temperature is shown indicates that, with the exception of the M-17 composition, the differences from expected behavior are not highly significant. The M-17, a triple-base propellant, is highly temperature dependent (Fig 41, p 82).

Past experience with M-17 propellant has shown that at a given low temperature, -52°C, the rate of pressure buildup as the pressure rises (i.e., dp/dt vs p) increases significantly. This sudden change of pressure with time has in some instances caused explosions in the barrel of the gun. Although this degree of burning has not been detected in the M-17 reported in this study, a definite reversal in burning rate at -21°C is noted at all pressures.

This trend is not evident, however, for two other triple-base propellants which were tested, M-15 and T-34. The difference in burning behavior between the two sets of propellants cannot at present be attributed to any single factor. There are, however, two apparent differences between the two sets of propellants, in grain dimensions and in flame temperatures. The web of the M-15 and T-34 propellants is much smaller than that of the M-17, .055 inch vs .0784 inch. The larger granulation is more susceptible to fissuring. The flame temperature of the M-17 is approximately 500°K higher. This may cause a greater temperature shock during burning and induce grain fissuring.

It is interesting to note the behavior of the T-36 propellant, which is a substitute for the M-17. Although this propellant follows the same general pattern as the M-17, the increase in burning rate between -20°C and -52°C is approximately 40% less than that of the M-17 (Fig 57, p 98). More data should be obtained on the T-36 propellant.

It is felt that all factors responsible for the increase in burning rate tend to produce an increase in surface area, with a subsequent apparent rise in burning rate. It is therefore recommended that a detailed study of the surface characteristics be made. This should include porosity and surface area measurements using a variety of techniques. The effect of extremely low temperatures on burning rate and surface area should also be studied. A study of this type would increase our understanding of the effects of temperature shock on the burning surface. This would help explain unstable burning at low temperatures.

An estimate of the temperature dependency of the burning rate is usually obtained by calculating a K_B factor for the propellant,

$$K_B = \frac{\Delta r / r_a}{\Delta T}$$

where

$\Delta r = r_a - r_t$ (in./sec)

r_a = burning rate at ambient temperature and at pressure P (in./sec)

r_t = burning rate at temperature t and pressure P (in./sec)

$\Delta T = T_a - T_t$ (difference between ambient and conditioning temperature of the propellant in °C).

The average K_B for a given propellant is calculated from K_B values determined at various pressure levels between 2,000 and 10,000 psi.

The K_B factors listed in Table 2 are calculated only where the rate of burning can be expressed by

$$r = BP^n$$

and where there is a linear relationship between rate and temperature. For this reason, K_B factors could not be calculated for the triple-base propellants and for some single- and double-base propellants. It must be noted that K_B

factors cannot necessarily be calculated for all propellants of a given class.

In a previous study (Ref 1), K_B factors of 0.002 were obtained for the double-base propellants M-2 and M-9. K_B factors for the single-base propellants reported in this study range from 0.0012 to 0.0016 (M-1, M-6, M-10). Although not all single- and double-base propellants can be characterized by the above factors, the general tendency is for the burning rate of the double-base propellant to be more temperature dependent.

The temperature dependency of burning rate can best be explained by the equation of Crow and Grinshaw (Ref 3)

$$r = \frac{c' p^n}{T' - T_c}$$

where

r = burning rate (in./sec)

c' = constant

p = pressure (psi)

n = pressure exponent

T' = surface temperature (°C)

T_c = initial temperature (°C)

It is evident from this equation that a high surface temperature causes r to become less temperature dependent. (This is also shown in the Arrhenius rate equation.) The surface temperature of the single base propellant must of necessity be higher than that of a double-base propellant. This can probably be explained as follows:

The first phase of propellant decomposition takes place at the surface where the propellant is broken down to volatile fragments, i.e., $R'ONO_2 \rightarrow R'O + NO_2$. The surface temperature can, therefore, be assumed to be the temperature of volatilization and initial decomposition. Vacuum stability tests, as well as other stability tests, show that nitroglycerin, a major constituent of double-base propellant, decomposes at a lower temperature and at a faster rate than nitrocellulose (Ref 4). Experience at Picatinny also shows that double-base propellants decompose more readily than single-base propellants. This indicates that the initial decomposition or volatilization temperature of a double-base propellant is more readily realized than that of a single-base propellant. In addition, nitroglycerin has a much lower vaporization temperature than nitrocellulose. This low-temperature physical transition from liquid to vapor with the concurrent absorption of heat should significantly reduce the surface temperature of propellants containing nitroglycerin.

According to this reasoning, the heat evolved on combustion brings the surface of the propellant to a relatively stable temperature. The higher flame temperature and greater heat evolved by propellants containing nitroglycerin increases the temperature of the surface at a rapid rate to the relatively low transition and decomposition temperature of the nitroglycerin and causes an increase in the rate of decomposition (burning rate).

A discussion of the effect of minor constituents on the surface temperature of a propellant would become extremely complicated. As is pointed out in Reference 3, some ingredients, such as dinitrotoluene, which decomposes at a higher temperature than any of the major ingredients, cause a higher surface temperature. The M-1 and M-6 propellants, therefore, with a 10% concentration of dinitrotoluene, have a lower burning rate coefficient (K_B) than the double-base propellants (Table 2).

Effect of Temperature on Maximum Pressure

The effect of temperature on maximum pressure is shown in Table 4 (p 11). The average percent reduction between -52°C and 21°C at 0.1Δ is 6.7%, and at 0.2Δ, 5.8%. Assuming ideal gas behavior, the closed bomb force or pressure as a function of temperature can be expressed by the law PV = Δn RT. If the reactions at -52°C and 21°C are assumed to be similar, maximum reduction of approximately 3% in PV can be anticipated in the flame temperature range 2500°K to 3500°K for a 70° to 80°C difference in initial temperature conditions.

That the observed data are not quantitative, however, is evident in Table 4. The difference in maximum pressure of the M-6 propellant at 0.1Δ varies between 1.7% and 17.1%.

Pressure-Burning Rate Relationship

The equation $r = BP^n$ is generally used in relating pressure and burning rate of gun propellants. This equation is, therefore, calculated for all propellants where log p vs log r is linear. Equation constants are listed in Table 2. It should be noted that although the equation can be applied to all types of propellants (M-1, M-2, etc), it cannot be calculated in all cases. For example, of the three M-1 propellants tested, only the single-perforated sample conformed to the equation (Fig 1, p 42). The apparent burning rates of the two multiperforated lots change abruptly at 6000 psi (Figs 5, 6, and 7, pp 46, 47, and 48).

Table 5 (p 12) shows the effect of heat loss on burning rate and maximum pressure. It is seen that in all cases propellants with smaller web (less burning time and therefore less heat loss) have higher maximum pressures. Burning rates are in general also higher for the smaller web propellants. The effect of the heat loss is to detract from the rate of pressure buildup (dp/dt), thus decreasing the burning rate. It should be noted that, in addition to the heat loss attributed to burning time, a correction must also be made for the expansion of the bomb and for the ratio of the surface area of the bomb to its capacity. If heat loss corrections are made to zero burning time, i.e., zero web, the burning rate of a given chemical composition as well as the maximum pressure would become independent of geometry.

An examination of the constants B and n for the various propellants shows that, in all cases where the burning rate can be expressed as $r = BP^n$, neither B nor n is constant over the temperature range in which measurements were made. (For M-1 propellant, see Table 7 (p 14); for M-2 propellant, Table 11 (p 18); for M-6, Table 15 (p 22); for M-10, Table 19 (p 26); for M-17, Table 25 (p 32); and for T-36, Table 34 (p 41)). This shows that propellant burning is contingent not only on pressure and temperature, but on other factors as well. A correction for heat losses in the bomb may, however, significantly reduce the variation in each of the constants. A comparison of burning rates obtained from the strand burner with those obtained from the closed bomb may prove helpful in solving this type of problem.

Effect of Loading Density (Δ) on Propellant Burning

The loading density has a double effect on the burning characteristics of a propellant. An increase in Δ reduces the reaction time (thereby reducing heat loss) and also causes a change in the reaction (due to differences in concentration and composition of products). The latter causes a pronounced change in maximum pressure developed by the propellant. Table 3 (p 10) shows the pressure per gram developed at 0.04 Δ and 0.2 Δ. It is noted that at the 0.2 Δ the pressure developed per gram is in some cases 70% higher that that at 0.04 Δ. The reason for this large difference could be determined by analyzing the gases evolved and by measuring the heat output at the different loading densities. The loading density effect warrants further study because it can show the optimum operating conditions of a propellant. This may prove useful not only for gun propellants, but for rocket propellants as well. In addition it may also indicate the pressures at which radical changes in burning rate occur.

EXPERIMENTAL

The burning characteristics at low temperature were determined in a closed bomb housed in a low temperature box. The detailed procedure and equipment are described in other reports (Refs 1 and 2).

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1. J. Harris and L. Shulman, *Burning Characteristics of Standard Propellants between 21°C and –51°C*, Picatinny Arsenal Technical Report 2558, Nov 1958

2. M. Weinstein and A. Pallingston, *Preliminary Study of M-2 and M-9 Propellants between 137°F and –65°F*, Picatinny Arsenal Technical Report 2240, June 1958

3. Lewis, Pease, and Taylor, Editors, *Combustion Processes* – Vol II (1956), Princeton University Press, Princeton, N. J., 1956

4. O. E. Sheffield, *Properties of Explosives of Military Interest*, Picatinny Arsenal Technical Report 1740, Rev. 1, April 1958 (Original report by W. R. Tomlinson)

5. F. R. W. Hunt, Editor, *Internal Ballistics*, Philosophical Library Inc., N. Y., 1951

TABLE 1

Composition of standard propellants

Propellant	M1	M2	M6	M10	M15	M17	T28	T34	T36
Nitrocellulose	85.0	77.45	87.0	98.0	20.0	22.0	67.25	20.0	29.13
(% Nitrogen)	(13.15)	(13.25)	(13.15)	(13.15)	(13.15)	(13.15)	(13.15)	(12.6)	(12.60)
Nitroglycerin		19.50			19.0	21.5	25.00	19.0	21.84
Barium nitrate		1.40					0.75		
Potassium nitrate		0.75		1.0			0.70		
Potassium sulfate				1.0					
Nitroguanidine					54.7	54.7		54.7	47.3
Dinitrotoluene	10.0		10.0						
Dibutylphthalate	5.0		3.0					4.0	
Diphenylamine	1.0*		1.0*						
2-Nitrodiphenylamine								2.0	
Ethyl centralite		0.60			6.0	1.5	6.0		1.47
Graphite		0.30		0.1**		0.1**	0.3		
Cryolite					0.30	0.30			0.26
Ethyl alcohol (residual)	0.75	2.30	0.90	1.5	0.30	0.30	1.20	0.30	
Water (residual)	0.50	0.70	0.50	0.5	0.00	0.00	0.30	0.00	
Isochoric flame temp, °K, Tv	2417	3319	2570	3000	2594	3017	3081	2608	3040

*Added.

**Glaze added.

TABLE 2

Burning rate equation constants ($r = BP^n$ at 21°C)

Propellant	Composition	$B \times 10^{-3}$	n	Λ*	K_B**
PA 6214	M-1	2.143	0.710	0.1	0.00165 (21°C to −40°C)
HPC 18891	M-2	2.432	0.755	0.1	
PAE 6124	M-2	1.781	0.820	0.1	0.00205 (Ref 1)
IND 8799	M-6	5.176	0.674	0.2	0.00119 (21°C to −40°C)
PAE 19121	M-6	–	–	0.1	0.00158
IOW 6667	M-6	2.989	0.702	0.2	
HEP 63016	M-9	1.845	0.850	0.1	0.00205 (Ref 1)
PA 30187	M-10	4.004	0.695	0.1	0.00123
RAD 38422	M-15	4.108	0.675	0.2	
RAD 38714	M-17	6.956	0.632	0.2	
PAE 25333	T-34	3.600	0.644	0.2	
SUN IS 604	T-34	3.563	0.650	0.2	
SUN IS 607	T-34	4.813	0.619	0.2	
Expt 5008C	T-36	5.762	0.652	0.2	

*Λ = loading density g/cc

**K_B = temperature coefficient of burning rate

TABLE 3

Some burning characteristics of propellants at 21°C in a 197-cc closed bomb

Lot	Composition	Type of Perforation	Weight of Sample, g	Maximum Pressure, psi	Pressure per Gram, psi	Time to Max Pressure, milliseconds
PA 6214	M-1	Single	40.00	36,100	900	8
			8.08	4,600	570	46
HPC 18891	M-2	Multi	39.40	41,100	1,045	13
			7.88	5,500	700	49
PAE 19121	M-6	Multi	39.40	35,000	890	14
			7.88	4,800	610	77
IND 8799	M-6	Multi	39.40	35,500	900	16
			7.88	5,000	635	45
IOW 6667	M-6	Multi	39.40	35,000	890	9
			7.88	4,600	585	42
PA 30187	M-10	Single	40.00	40,100	1,000	3
			8.08	6,170	765	15
RAD 35626	M-10	Multi	39.40	39,100	990	7
			7.88	5,600	710	31
RAD 38422	M-15	Multi	39.40	37,000	940	23
			7.88	4,800	610	80+
RAD 38714	M-17	Multi	39.40	38,900	990	18
			7.88	4,900	620	80
RAD 60470	T-28	Multi	39.40	39,500	1,000	7
			7.88	4,900	620	35
PAE 25333	T-34	Multi	39.40	36,600	930	8
			7.88	4,200	535	35
Expt 5008C	T-36	Multi	39.40	38,700	980	12
			7.88	5,100	650	45

TABLE 4

Effect of temperature on maximum pressure

Propellant	Composition	Web, in.	Maximum Pressure, psi 21°C	Maximum Pressure, psi −52°C	Percent Decrease 21°C to −52°C
			0.1Λ		
PA 6214	M-1	0.270	14,190	13,150	7.3
RAD 60444	M-1	0.0334	13,500	13,520	0.0
HPC 18891	M-2	0.0598	16,590	15,100	9.0
IOW 6667	M-6	0.0229	15,350	14,220	7.4
IND 8799	M-6	0.0491	13,560	12,200	10.0
PAE 19121	M-6	0.0498	13,200	12,780	3.2
PAE-21378	M-6	0.0574	13,840	13,600	1.7
IA 39789	M-6	0.0726	13,750	11,400	17.1
PA 30187	M-10	0.0179	15,900	14,800	6.9
RAD 35626	M-10	0.0335	15,420	15,440	0.0
PA 30257	M-10	0.0400	15,560	14,100	9.4
RAD 60470	T-28	–	16,200	14,750	8.9
			0.2Λ		
IOW 6667	M-6	0.0229	35,000	31,860	9.0
IND 8799	M-6	0.0491	35,500	31,740	10.6
RAD 38422	M-15	0.0550	37,000	33,700	8.9
RAD 38714	M-17	0.0784	38,900	36,500	6.2
SUN 604	T-34	0.0380	35,100	34,000	3.1
PAE 25333	T-34	0.0298	37,150	33,900	8.7
Expt 5008C	T-36	0.0840	38,700	36,570	5.5

TABLE 5

Effect of web on burning characteristics at 0.1Δ and 21°C

Sample	Web, in.	Perforation	Burning Rate 2,500 psi, in./sec	Burning Rate 5,000 psi, in./sec	Burning Rate 10,000 psi, in./sec	Burning Time to max P, ms	Maximum Pressure, psi
				M-1			
6,214	0.0270	Single	0.450	0.90	1.50	16.7	14,400
60,444	0.0334	Multi	0.370	1.00	1.30	–	13,490
36,602	0.0249	Multi	0.450	0.98	1.30	–	14,585
				M-2			
18,891	0.0598	Multi	0.88	1.50	2.6	26	16,800
6,124	0.0348	Single	1.08	1.80	3.5	8	17,200
				M-6			
21,378	0.0574	Multi	0.587	1.05	1.65	–	13,850
19,121	0.0498	Multi	0.620	1.05	1.55	25	14,200
				M-10			
30,187	0.0179	Single	0.88	1.49	2.4	5	18,000
35,626	0.0335	Multi	0.88	1.45	2.1	12	16,600
30,257	0.0400	Multi	0.81	1.35	2.1	–	15,560

TABLE 6

PA-6214 (M-1) single perforated for 37 mm gun
(Length - 0.2765 in., diameter - 0.0731 in., web 0.0270 in.)

Temperature, °C	Pressure, psi	Burning Rate, in./sec
21	2,520	0.450
	4,330	0.826
	6,150	1.030
	7,960	1.267
	9,780	1.464
	11,600	1.650
0	2,520	0.410
	4,330	0.778
	6,150	0.978
	7,960	1.196
	9,780	1.376
	11,600	1.528
-20	2,460	0.350
	4,220	0.766
	5,990	0.966
	7,750	1.178
	9,510	1.344
	11,270	1.481
-40	2,630	0.422
	4,560	0.802
	6,490	1.003
	8,420	1.210
	10,350	1.353
-52	2,580	0.456
	4,450	0.851
	6,330	1.062
	8,200	1.254
	10,080	1.392

TABLE 7

PA-6214 (M-1) single perforated for 37 mm gun*
(Length - 0.2765 in., diameter - 0.0731 in., web - 0.0270 in.)

Temperature, °C	Pressure, psi	Burning Rate,** in./sec
21	2,500	0.554
	4,300	0.814
	6,000	1.032
	8,000	1.265
	10,100	1.493
0	2,500	0.531
	4,300	0.773
	6,000	0.974
	8,000	1.188
	10,100	1.397
-20	2,500	0.539
	4,300	0.778
	6,000	0.976
	8,000	1.187
	10,100	1.390
-40	2,500	0.539
	4,300	0.769
	6,000	0.957
	8,000	1.156
	10,100	1.347
-52	2,500	0.584
	4,300	0.815
	6,000	1.000
	8,000	1.194
	10,100	1.378
	Burning Rate Constants	
21	$B \times 10^{-3}$	2.143
	n	0.710
0	$B \times 10^{-3}$	2.345
	n	0.693
-20	$B \times 10^{-3}$	2.655
	n	0.679
-40	$B \times 10^{-3}$	3.180
	n	0.656
-52	$B \times 10^{-3}$	4.790
	n	0.615

*K_B = 0.00165 (21 to −40°C only).

**Calculated from least square equation $r = BP^n$.

TABLE 8

RAD-60444 (M-1) multiperforated for 155 mm gun
(Length - 0.4033 in., diameter - 0.1763 in., web - 0.0334 in.)

Temperature, °C	Pressure, psi	Burning Rate, in./sec
21	2,460	0.368
	4,220	0.865
	5,950	1.161
	7,750	1.212
	9,510	1.280
0	2,500	0.315
	4,290	0.833
	6,090	1.157
	7,880	1.311
	9,680	1.265
-20	2,500	0.290
	4,290	0.805
	6,090	1.144
	7,880	1.263
	9,680	1.182
-40	2,500	0.274
	5,000	0.734
	7,500	1.074
	10,000	1.257
	12,500	1.206
-52	2,500	0.287
	5,000	0.756
	7,500	1.070
	10,000	1.217
	12,500	1.164

TABLE 9

PAB-36602 (M-1) multiperforated for 105 mm gun
(Length - 0.3393 in., diameter - 0.1383 in., web - 0.0249 in.)

Temperature, °C	Pressure, psi	Burning Rate, in./sec
21	2,330	0.399
	3,970	0.781
	5,600	1.057
	7,240	1.235
	8,870	1.258
0	2,330	0.268
	3,970	0.721
	5,600	1.021
	7,240	1.226
	8,870	1.224
-20	2,435	0.305
	4,170	0.870
	5,910	1.161
	7,640	1.281
-40	2,440	0.265
	4,170	0.760
	5,910	1.076
	7,640	1.183
-52	2,330	0.284
	3,970	0.780
	3,900	1.103
	7,240	1.100
	8,870	1.135

TABLE 10

HPC-18891 (M-2) multiperforated .or 76 mm gun
(Length - 0.8718 in., diameter - 0.4320 in., web - 0.0598 in.)

Temperature, °C	Pressure, psi	Burning Rate, in./sec
21	2,900	0.901
	5,100	1.528
	7,300	2.012
	9,500	2.435
	11,500	2.861
0	2,900	0.928
	5,000	1.553
	7,200	2.008
	9,300	2.440
	11,500	2.759
−20	2,800	0.986
	4,900	1.558
	7,000	2.017
	9,000	2.430
	11,000	2.704
−40	2,800	0.825
	4,900	1.446
	7,000	1.922
	9,000	2.335
	11,100	2.611
−52	2,900	1.051
	5,000	1.584
	7,200	2.004
	9,300	2.254
	11,500	2.514

TABLE 11

HPC-18891 (M-2) multiperforated
(Length - 0.8718 in., diameter - 0.4320 in., web - 0.0598 in.)

Temperature, °C	Pressure, psi	Burning Rate,* in./sec
21	3,000	1.026
	5,000	1.509
	7,000	1.945
	9,000	2.352
	11,000	2.736
0	3,000	1.087
	5,000	1.557
	7,000	1.973
	9,000	2.355
	11,000	2.712
-20	3,000	1.125
	5,000	1.587
	7,000	1.990
	9,000	2.357
	11,000	2.697
-40	3,000	1.025
	5,000	1.523
	7,000	1.904
	9,000	2.287
	11,000	2.649
-52	3,000	1.213
	5,000	1.607
	7,000	1.934
	9,000	2.220
	11,000	2.478

Burning Rate Constants

	$B \times 10^{-3}$	n
21	2.432	0.755
0	3.874	0.704
-20	5.142	0.673
-40	2.943	0.731
-52	14.840	0.550

*Calculated from least square equation $r = BP^n$

TABLE 12

PAE-21378 (M-6) multiperforated
(Length - 1.0224 in., diameter - 0.3237 in., web - 0.0574 in.)

Temperature, °C	Pressure, psi	Burning Rate, in./sec
21	2,500	0.587
	4,200	0.903
	6,000	1.180
	7,800	1.446
	9,500	1.559
	11,300	1.657
0	2,500	0.579
	4,300	0.928
	6,100	1.239
	7,900	1.459
	9,700	1.515
	11,500	1.566
-20	2,500	0.543
	4,300	0.913
	6,100	1.234
	7,900	1.430
	9,700	1.445
-40	2,500	0.481
	4,200	0.805
	6,000	1.135
	7,700	1.401
	9,400	1.467
-52	2,500	0.506
	4,200	0.859
	6,000	1.189
	7,700	1.395
	9,400	1.408

TABLE 13

PAE-19121 (M-6) multiperforated for 90 mm gun*
(Length - 0.6213 in., diameter - 0.2866 in., web - 0.0498 in.)

Temperature, °C	Pressure, psi	Burning Rate, in./sec
21	2,500	0.620
	4,400	0.947
	6,200	1.182
	8,000	1.373
	9,800	1.500
0	2,500	0.611
	4,400	0.958
	6,200	1.201
	8,000	1.340
	9,800	1.402
−20	2,500	0.564
	4,300	0.893
	6,100	1.129
	7,900	1.279
	9,700	1.370
−40	2,500	0.496
	4,400	0.824
	6,200	1.087
	8,000	1.241
	9,800	1.295
−52	2,500	0.539
	4,300	0.870
	6,100	1.114
	7,900	1.216
	9,700	1.287

*K_B = 0.00158 or 1.6% decrease in burning rate per 10°C decrease in temperature.

TABLE 14

IND-8799 (M-6) multiperforated for 90 mm AA gun
(Length - 0.6626 in., diameter - 0.2779 in., web - 0.0491 in.)

Temperature, °C	Pressure, psi	Burning Rate, in./sec
21	4,900	1.536
	9,000	2.486
	13,200	3.165
	17,400	3.708
	21,500	4.208
0	4,700	1.476
	8,800	2.407
	12,800	3.144
	16,800	3.654
	20,900	3.997
20	4,600	1.295
	8,500	2.189
	12,400	2.887
	16,400	3.339
	20,300	3.811
–40	4,700	1.388
	8,800	2.290
	12,800	2.942
	16,800	3.373
	20,900	3.650
–52	4,600	1.300
	8,500	2.100
	12,400	2.910
	16,400	3.340
	20,300	3.610

TABLE 15

IND-8799 (M-6) multiperforated for 90 mm AA gun*
(Length - 0.6626 in., diameter - 0.2779 in., web - 0.0491 in.)

Temperature, °C	Pressure, psi	Burning Rate,** in./sec
21	5,000	1.611
	9,000	2.397
	13,000	3.068
	17,000	3.675
	21,000	4.239
0	5,000	1.585
	9,000	2.367
	13,000	3.041
	17,000	3.652
	21,000	4.218
-20	5,000	1.437
	9,000	2.187
	13,000	2.855
	17,000	3.471
	21,000	4.045
-40	5,000	1.504
	9,000	2.219
	13,000	2.829
	17,000	3.378
	21,000	3.884
-52	5,000	1.425
	9,000	2.159
	13,000	2.801
	17,000	3.385
	21,000	3.931

Burning Rate Constants

	$B \times 10^{-3}$	n
21	5.176	0.674
0	4.757	0.682
-20	2.944	0.726
-40	5.399	0.661
-52	3.457	0.707

* K_B = 0.001185 or 1.2% decrease in burning rate per 10°C decrease in temperature.

** Calculated from least square equation $r = BP^n$.

TABLE 16

IOW-6667 (M-6) multiperforated for 37 mm gun
(Length - 0.3258 in., diameter - 0.1307 in., web - 0.0229 in.)

Temperature, °C	Pressure, psi	Burning Rate, in./sec
21	4,900	1.152
	9,000	1.779
	13,200	2.368
	17,400	2.867
	22,000	3.213
0	4,700	1.201
	8,800	1.896
	12,800	2.475
	16,900	2.906
	20,900	3.186
-20	4,600	0.962
	8,500	1.754
	12,400	2.334
	16,400	2.740
	20,300	2.979
-40	4,700	1.037
	8,800	1.764
	12,800	2.363
	16,800	2.795
	20,900	3.051
-52	4,800	1.168
	8,900	1.883
	13,000	2.526
	17,000	2.906
	21,200	3.164

TABLE 17

IOW-6667 (M-6) multiperforated for 37 mm gun
(Length - 0.3258 in., diameter - 0.1307 in., web - 0.0229 in.)

Temperature, °C	Pressure, psi	Burning Rate,* in./sec
21	5,000	1.181
	9,000	1.784
	13,000	2.310
	17,000	2.788
	21,000	3.234
	Burning Rate Constants	
	$B \times 10^{-3}$	n
21	2.989	0.702

*Calculated from least square equation $r = BP^n$.

TABLE 18

PA-30187 (M-10) single perforated for 57 mm gun
(Length - 0.1351 in., diameter - 0.0492 in., web - 0.0179 in.)

Temperature, °C	Pressure, psi	Burning Rate, in./sec
21	2,800	0.971
	4,900	1.482
	7,000	1.834
	9,000	2.241
	11,100	2.618
	13,200	2.944
0	2,900	0.850
	5,000	1.454
	7,200	1.799
	9,300	2.174
	11,560	2.492
-20	2,800	0.892
	4,900	1.438
	7,100	1.775
	9,200	2.136
	11,300	2.454
-40	2,800	0.841
	4,900	1.389
	7,000	1.704
	9,000	2.076
	11,100	2.404
-52	2,900	0.914
	5,000	1.414
	7,200	1.780
	9,300	2.134
	11,500	2.422

TABLE 19

PA-30187 (M-10) single perforated for 57 mm gun
(Length - 0.1351 in., diameter - 0.0492 in., web - 0.0179 in.)

Temperature, °C	Pressure, psi	Burning Rate,* in./sec
21	3,000	1.045
	5,000	1.490
	7,000	1.883
	9,000	2.242
	11,000	2.578
0	3,000	1.037
	5,000	1.446
	7,000	1.799
	9,000	2.119
	11,000	2.414
−20	3,000	1.038
	5,000	1.443
	7,000	1.792
	9,000	2.106
	11,000	2.397
−40	3,000	0.987
	5,000	1.393
	7,000	1.748
	9,000	2.071
	11,000	2.372
−52	3,000	1.017
	5,000	1.416
	7,000	1.762
	9,000	2.073
	11,000	2.361

Burning Rate Constants

	$B \times 10^{-3}$	n
21	4.004	0.695
0	5.699	0.650
−20	5.984	0.644
−40	4.437	0.675
−52	5.679	0.648

*Calculated from least square equation $r = BP^n$.

TABLE 20

RAD-35626 (M-10) multiperforated for 105 mm rifle
(Length - 0.4443 in., diameter - 0.1992 in., web - 0.0335 in.)

Temperature, °C	Pressure, psi	Burning Rate, in./sec
21	2,800	0.940
	4,900	1.376
	7,000	1.820
	9,000	2.069
	11,100	2.183
0	2,700	0.874
	4,700	1.337
	6,700	1.720
	8,700	1.960
	10,700	2.038
-20	2,700	0.910
	4,700	1.442
	6,700	1.810
	8,700	1.927
	10,700	1.952
-40	2,900	0.910
	5,000	1.442
	7,200	1.810
	9,300	1.927
	11,500	1.952
-52	2,800	0.789
	4,700	1.295
	6,800	1.702
	8,800	1.868
	10,800	1.910

TABLE 21

PAE-30257 (M-10) multiperforated for 106 mm rifle
(Length - 0.4681 in., diameter - 0.2241 in., web - 0.0400 in.)

Temperature, °C	Pressure, psi	Burning Rate, in./sec
21	2,500	0.811
	4,300	1.216
	6,200	1.610
	8,000	1.925
	9,800	2.127
	11,600	2.201
0	2,500	0.741
	4,300	1.158
	6,200	1.543
	8,000	1.825
	9,800	2.018
	11,600	2.106
-20	2,500	0.691
	4,200	1.120
	6,000	1.532
	7,800	1.807
	9,500	2.002
	11,300	2.082
-40	2,600	0.760
	4,600	1.2[illegible]7
	6,500	1.581
	8,400	1.830
	10,400	1.940
-52	2,600	0.751
	4,500	1.343
	6,300	1.750
	8,200	1.997
	10,100	2.068

TABLE 22

RAD-38422 (M-15) multiperforated for 90 mm gun
(Length - 0.6747 in., diameter - 0.2959 in., web - 0.0550 in.)

Temperature, °C	Pressure, psi	Burning Rate, in./sec
21	5,400	1.325
	10,000	2.076
	14,600	2.683
	19,300	3.179
	24,000	3.670
0	5,500	1.362
	10,300	2.111
	15,000	2.660
	20,000	3.124
	24,700	3.530
-20	5,500	1.325
	10,300	2.036
	15,000	2.530
	20,000	2.901
	24,700	3.261
-40	5,400	1.494
	10,000	2.161
	14,600	2.588
	19,300	2.912
	24,000	3.218
-52	5,300	1.333
	9,900	2.142
	14,400	2.604
	19,000	2.827
	23,600	3.051

TABLE 23

RAD-38422 (M-15) multiperforated for 90 mm gun
(Length - 0.6747 in., diameter - 0.2959 in., web - 0.0550 in.)

Temperature, °C	Pressure, psi	Burning Rate,* in./sec
21	5,300	1.339
	10,000	2.051
	14,600	2.655
	19,300	3.197
	24,000	3.698

Burning Rate Constants

	$B \times 10^{-3}$	n
21	4.108	0.675

*Calculated from least square equation $r = BP^n$.

TABLE 24

RAD-38714 (M-17) multiperforated for 90 mm gun
(Length - 1.1437 in., diameter - 0.4733 in., web - 0.0784 in.)

Temperature, °C	Pressure, psi	Burning Rate, in./sec
21	5,600	1.643
	10,600	2.379
	15,500	3.093
	20,400	3.716
	25,400	4.243
	30,300	4.682
0	5,400	1.415
	10,100	2.169
	14,800	2.815
	19,500	3.428
	24,200	3.992
	29,000	4.364
−20	5,600	1.352
	10,400	2.021
	15,300	2.639
	20,100	3.160
	25,000	3.677
	30,000	4.010
−40	5,500	1.471
	10,300	2.165
	15,000	2.784
	19,800	3.301
	24,600	3.731
−52	5,400	1.571
	10,100	2.368
	14,800	2.994
	19,500	3.463
	24,200	3.779

TABLE 25

RAD-38714 (M-17) multiperforated for 90 mm gun
(Length - 1.1437 in., diameter - 0.4733 in., web - 0.0784 in.)

Temperature, °C	Pressure, psi	Burning Rate,* in./sec
21	5,000	1.514
	9,000	2.195
	13,000	2.769
	17,000	3.281
	21,000	3.750
	25,000	4.188
0	5,000	1.342
	9,000	2.004
	13,000	2.576
	17,000	3.093
	21,000	3.572
	25,000	4.023
−20	5,000	1.260
	9,000	1.853
	13,000	2.360
	17,000	2.815
	21,000	3.234
	25,000	3.625
−40	5,000	1.394
	9,000	2.008
	13,000	2.523
	17,000	2.980
	21,000	3.399
	25,000	3.779
−52	5,000	1.530
	9,000	2.169
	13,000	2.698
	17,000	3.164
	21,000	3.587
	25,000	3.977

Burning Rate Constants

	$B \times 10^{-3}$	n
21	6.956	0.632
0	4.029	0.682
−20	4.678	0.657
−40	7.034	0.621
−52	9.712	0.594

*Calculated from least square equation $r = BP^n$.

TABLE 26

RAD-60470 (T-28) multiperforated for 106 mm rifle
(Length - 0.5144 in., diameter - 0.1500 in., web - 0.0380 in.)

Temperature, °C	Pressure, psi	Burning Rate, in./sec
21	2,700	0.794
	4,600	1.430
	6,600	1.911
	8,500	2.273
	10,500	2.453
	12,500	2.722
0	2,700	0.748
	4,700	1.384
	6,700	1.895
	8,600	2.186
	10,600	2.374
	12,600	2.576
-21	2,700	0.800
	4,600	1.406
	6,500	1.895
	8,500	2.184
	10,400	2.304
	12,300	2.373
-40	2,700	0.605
	4,600	1.328
	6,600	1.855
	8,600	2.162
	10,500	2.264
	12,500	2.318
-52	2,700	0.905
	4,800	1.506
	6,800	1.972
	8,800	2.218
	10,900	2.270

TABLE 27

PAE-25333 (T-34) multiperforated for 90 mm gun
(Length - 0.3711 in., diameter - 0.1603 in., web - 0.0298 in.)

Temperature, °C	Pressure, psi	Burning Rate, in./sec
21	5,100	0.883
	9,400	1.296
	13,800	1.648
	18,200	2.005
	22,600	2.296
0	5,100	1.320
	9,400	1.628
	13,800	1.836
	18,200	2.138
	22,600	2.390
-20	5,100	1.547
	9,400	1.905
	13,800	1.999
	18,200	2.161
	22,600	2.336
-40	5,100	1.260
	9,400	2.033
	13,200	2.192
	18,200	2.167
	22,600	2.221
-52	5,100	1.416
	9,400	2.106
	13,200	2.287
	18,200	2.206
	22,600	2.198

TABLE 28

PAE-25333 (T-34) multiperforated for 90 mm gun
(Length - 0.3711 in., diameter - 0.1603 in., web - 0.0298 in.)

Temperature, °C	Pressure, psi	Burning Rate,* in./sec
21	5,000	0.868
	9,000	1.267
	13,000	1.606
	17,000	1.909
	21,000	2.187

Burning Rate Constants

	$B \times 10^{-3}$	n
21	3.600	0.644

*Calculated from least square equation $r = BP^n$.

TABLE 29

SUN-IS-604 (T-34) multiperforated for 90 mm gun
(Length - 0.550 in., diameter - 0.241 in., web - 0.038 in.)

Temperature, °C	Pressure, psi	Burning Rate, in./sec
21	5,300	0.945
	10,000	1.401
	14,600	1.807
	19,300	2.211
	24,000	2.487
0	5,500	1.046
	10,300	1.396
	15,000	1.740
	20,000	2.083
	24,700	2.339
-20	5,500	1.021
	10,300	1.410
	15,000	1.695
	20,000	1.958
	24,700	2.164
-40	5,300	1.252
	10,000	1.639
	14,600	1.898
	19,300	2.026
	24,000	2.123
-52	5,300	1.123
	9,900	1.614
	14,400	1.890
	19,000	1.984
	23,600	2.066

TABLE 30

SUN-IS-604 (T-34) multiperforated for 90 mm gun
(Length - 0.550 in., diameter - 0.241 in., web - 0.038 in.)

Temperature, °C	Pressure, psi	Burning Rate,* in./sec
21	5,300	0.940
	10,000	1.417
	14,600	1.816
	19,300	2.174
	24,000	2.502

Burning Rate Constants

	$B \times 10^{-3}$	n
21	3.563	0.650

*Calculated from least square equation $r = BP^n$.

TABLE 31

SUN-IS-607 (T-34) multiperforated for 90 mm gun
(Length - 0.554 in., diameter - 0.235 in. web - 0.038 in.)

Temperature, °C	Pressure, psi	Burning Rate, in./sec
21	5,300	0.993
	10,000	1.390
	14,600	1.813
	19,300	2.191
	24,000	2.493
0	5,500	1.049
	10,300	1.365
	15,000	1.771
	20,000	2.098
	24,700	2.331
-20	5,500	1.031
	10,300	1.389
	15,000	1.685
	20,000	1.978
	24,700	2.183
-40	5,300	1.283
	10,000	1.649
	14,600	1.893
	19,300	2.128
	24,000	2.262
-52	5,300	1.113
	9,900	1.599
	14,400	1.865
	19,000	2.075
	23,600	2.215

TABLE 32

SUN-IS-607 (T-34) multiperforated for 90 mm gun
(Length - 0.554 in., diameter - 0.235 in., web - 0.038 in.)

Temperature, °C	Pressure, psi	Burning Rate,* in./sec
21	5,300	0.973
	10,000	1.440
	14,600	1.824
	19,300	2.163
	24,000	2.474
	Burning Rate Constants	
	$B \times 10^{-3}$	n
21	4.813	0.619

*Calculated from least square equation $r = BP^n$.

TABLE 33

Expt. 5008C (T-36) multiperforated for 90 mm gun
(Length - 1.023 in., diameter - 0.472 in., web - 0.084 in.)

Temperature, °C	Pressure, psi	Burning Rate, in./sec
21	5,600	1.620
	10,600	2.384
	15,500	3.104
	20,500	3.758
	25,400	4.356
	30,300	4.750
0	5,400	1.347
	10,100	2.177
	14,800	2.836
	19,500	3,464
	24,200	4.023
	29,000	4.437
-20	5,600	1.249
	10,400	2.031
	15,300	2.664
	20,100	3.221
	25,000	3.709
	29,800	4.040
-40	5,500	1.301
	10,300	2.076
	15,000	2.711
	19,800	3.259
	24,600	3.749
-52	5,400	1.350
	10,100	2.126
	14,800	2.795
	19,500	3.316
	24,200	3.769

TABLE 34

Expt. 5008C (T-36) multiperforated
(Length - 1.023 in., diameter - 0.472 in., web - 0.084 in.)

Temperature, °C	Pressure, psi	Burning Rate,* in./sec
21	5,000	1.487
	9,000	2.181
	13,000	2.772
	17,000	3.302
	21,000	3.790
	25,000	4.247
0	5,000	1.291
	9,000	1.968
	13,000	2.561
	17,000	3.105
	21,000	3.612
	25,000	4.090
-20	5,000	1.190
	9,000	1.799
	13,000	2.331
	17,000	2.815
	21,000	3.267
	25,000	3.691
-40	5,000	1.236
	9,000	1.868
	13,000	2.420
	17,000	2.922
	21,000	3.393
	25,000	3.834
-52	5,000	1.296
	9,000	1.942
	13,000	2.502
	17,000	3.010
	21,000	3.482
	25,000	3.927

Burning Rate Constants

	$B \times 10^{-3}$	n
21	5.762	0.652
0	2.876	0.717
-20	2.460	0.704
-40	3.102	0.703
-52	3.663	0.684

*Calculated from least square equation $r = BP^n$.

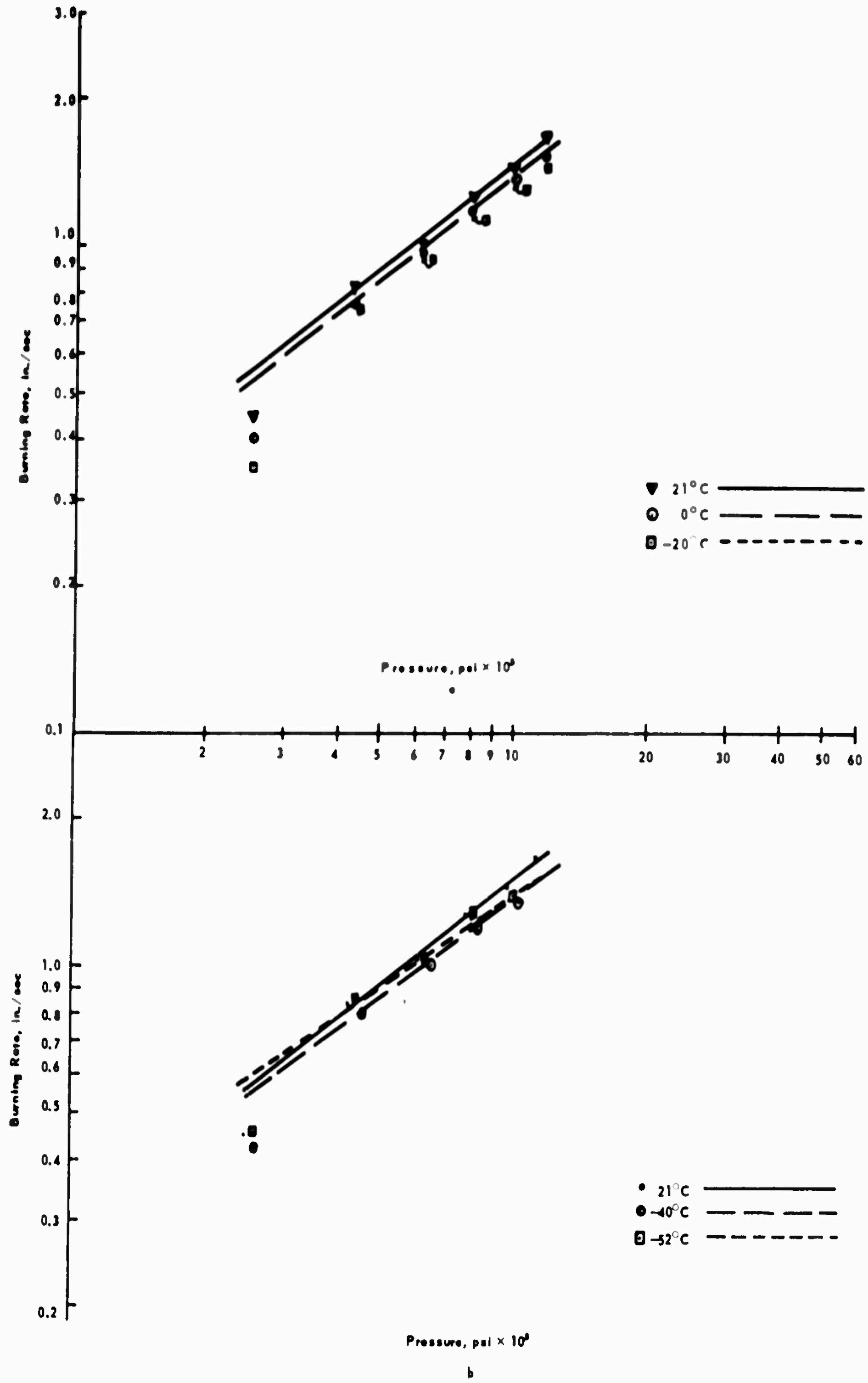

Fig 1 Burning rate vs pressure. M1 propellant, PA-6214. 0.1Δ

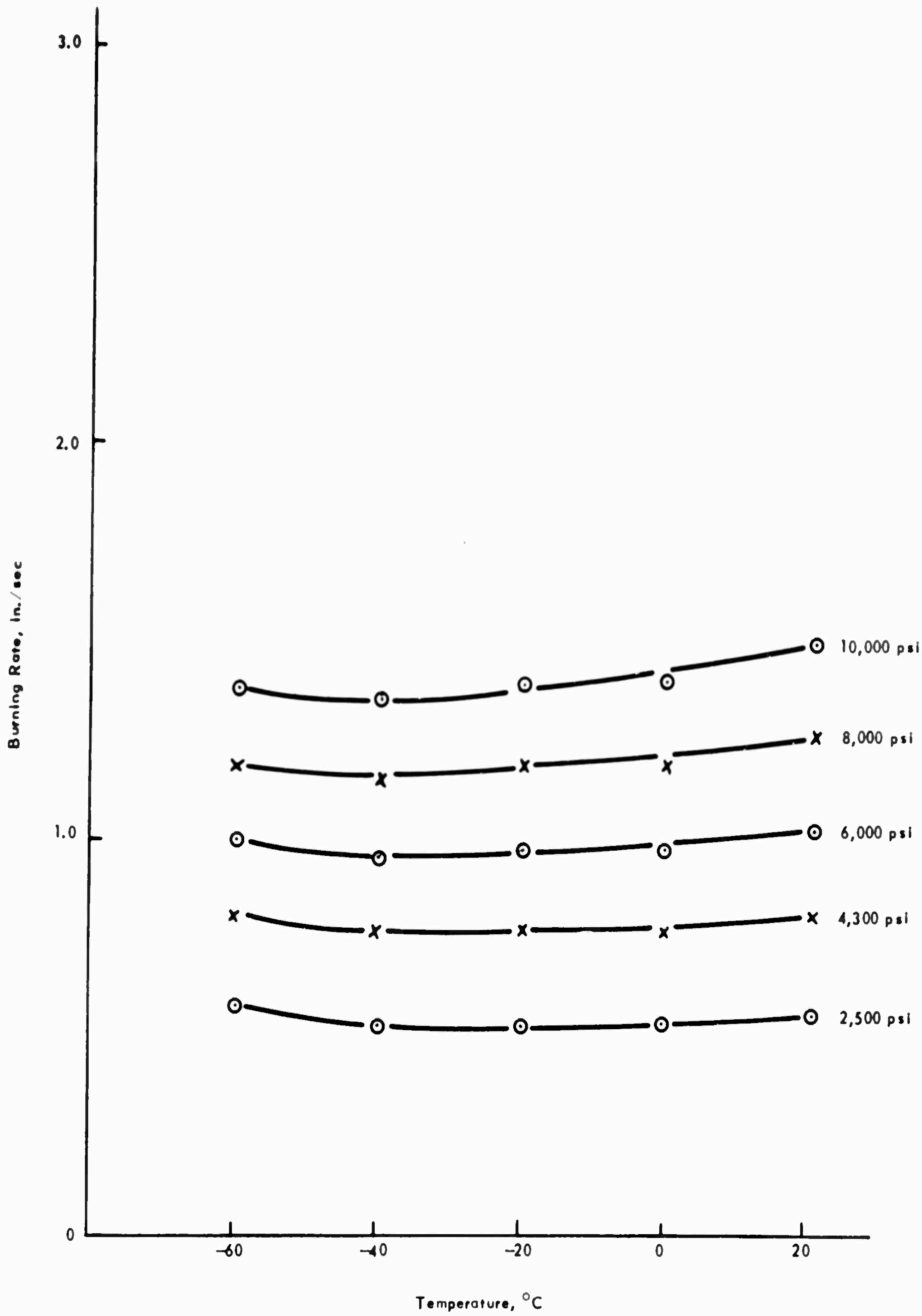

Fig 2   Burning rate (from least square curve) vs temperature. M1 propellant, PA-6214

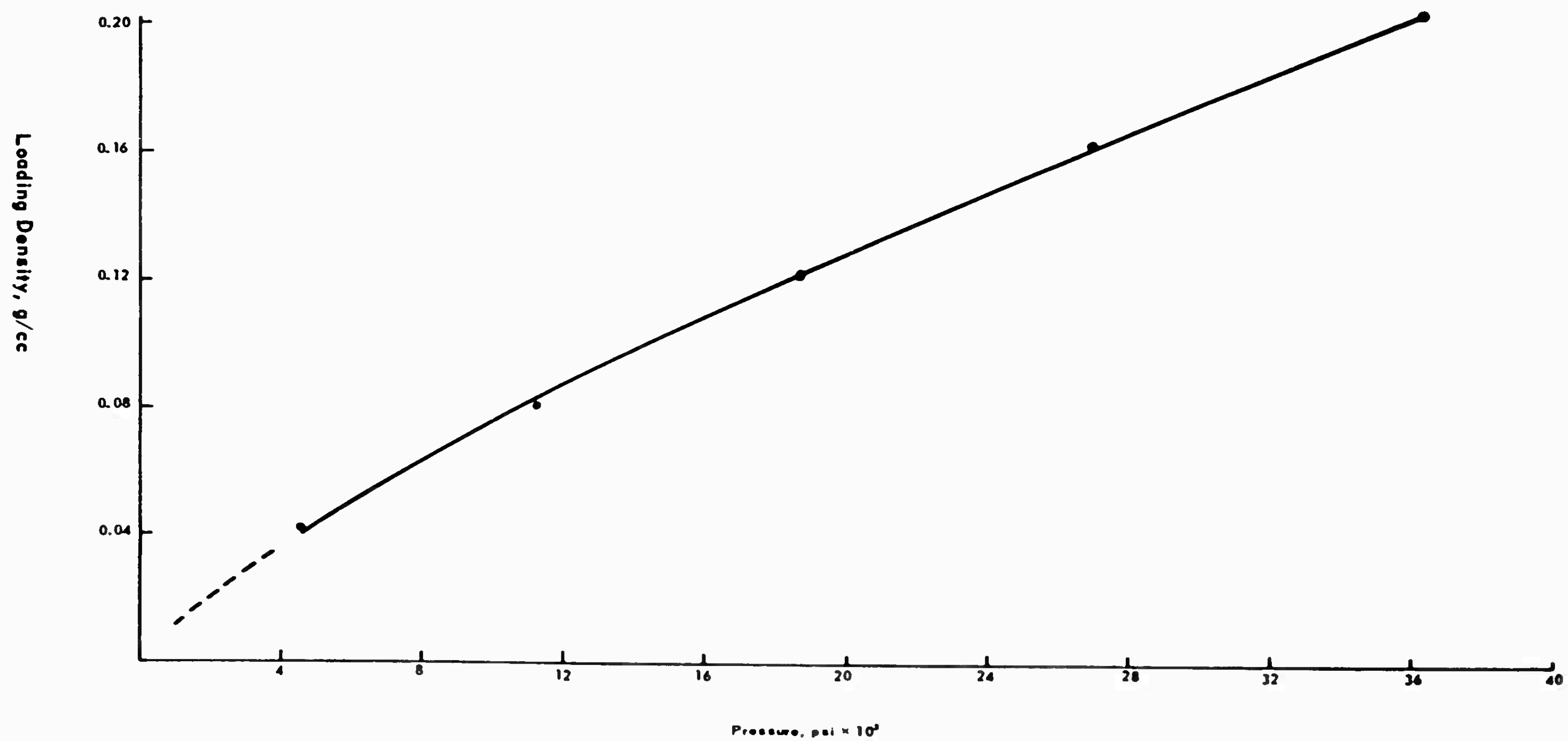

Fig 3 Loading density vs pressure. M1 propellant, PA-6214

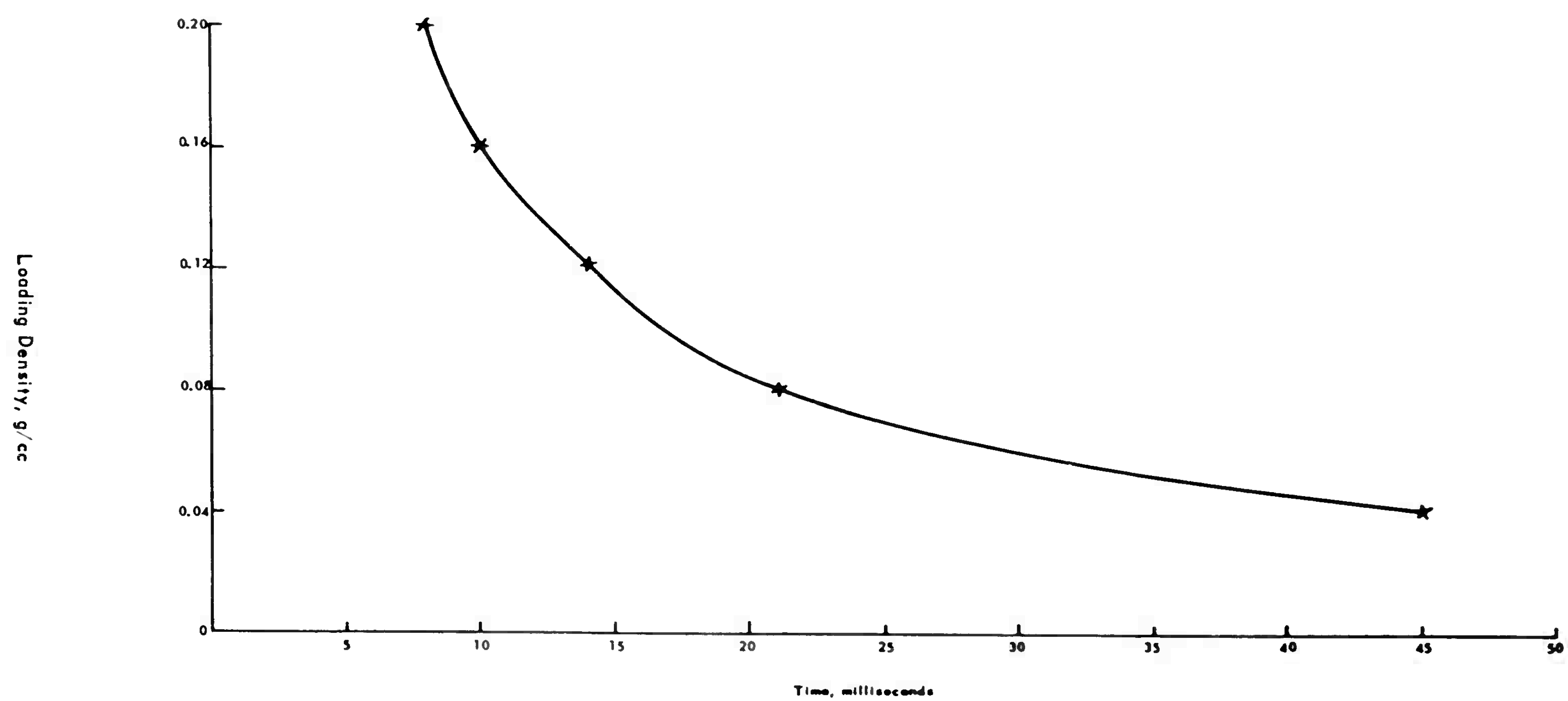

Fig 4 Loading density vs time of burning. M-1 propellant, PA-6214

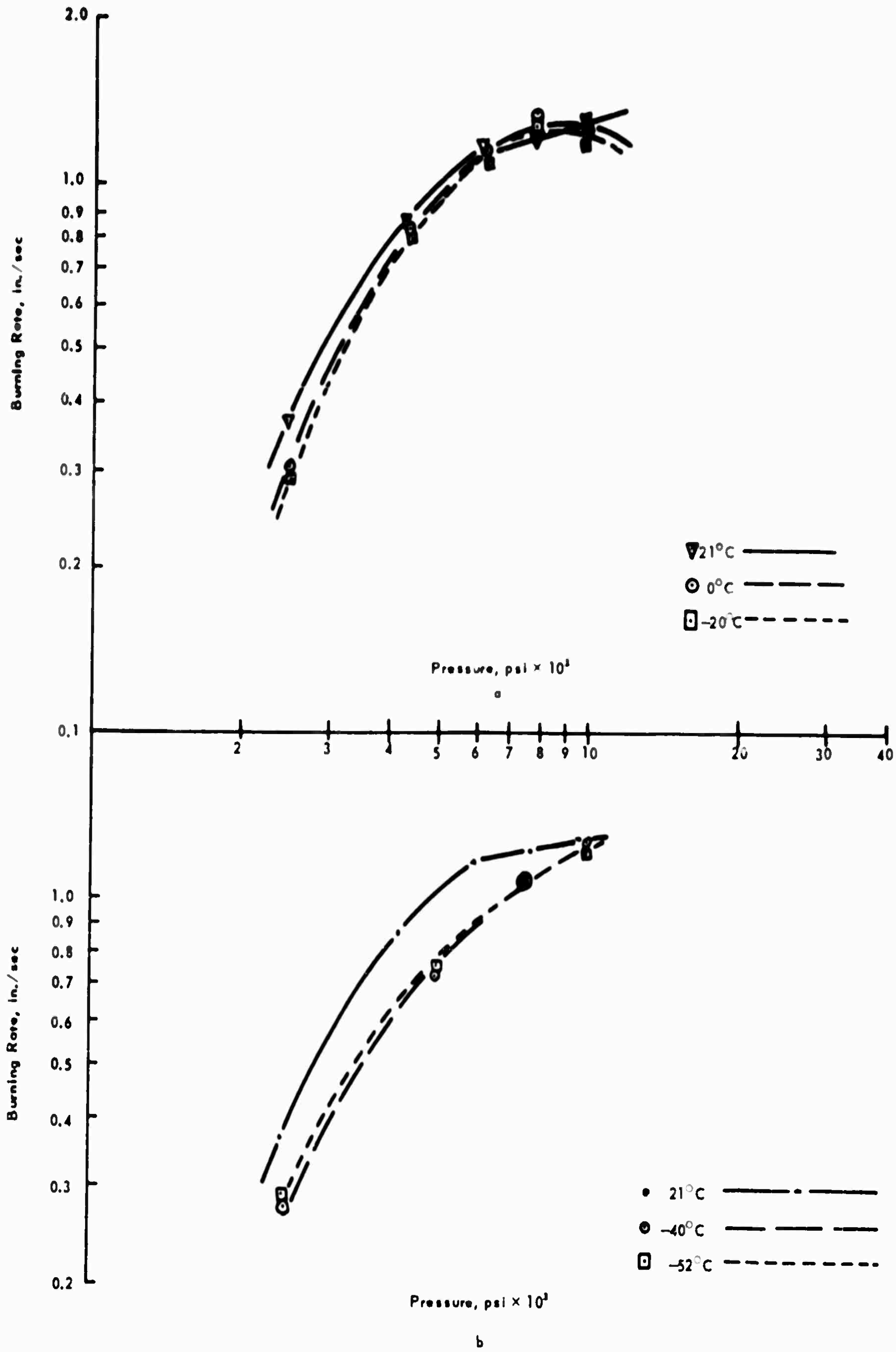

Fig 5 Burning rate vs pressure. M-1 propellant, RAD-60444. 0.1Δ

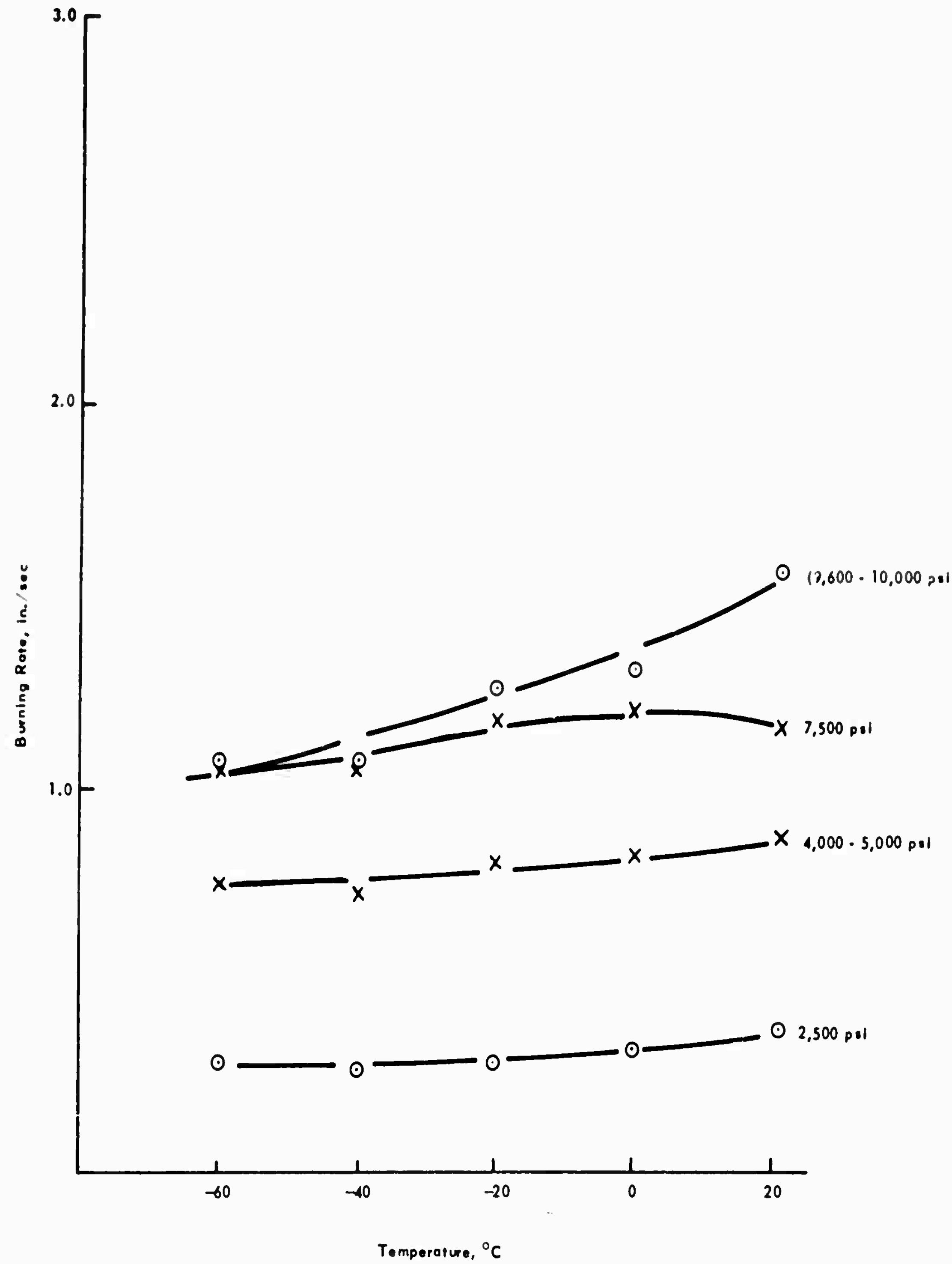

Fig 6 Burning rate vs temperature. M-1 propellant, RAD-60444

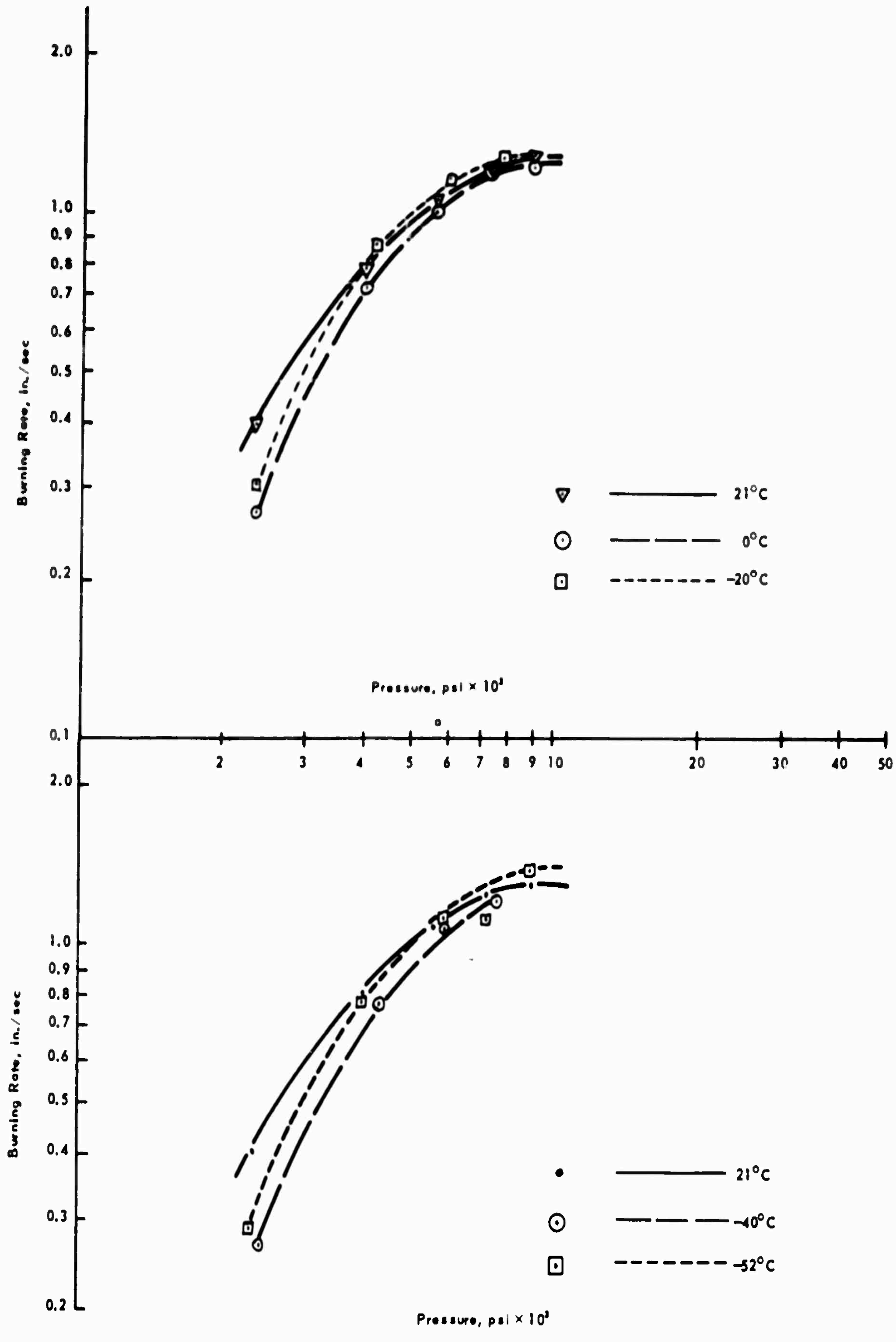

Fig 7 Burning rate vs pressure. M-1 propellant blend, PAB-36602. 0.1Δ

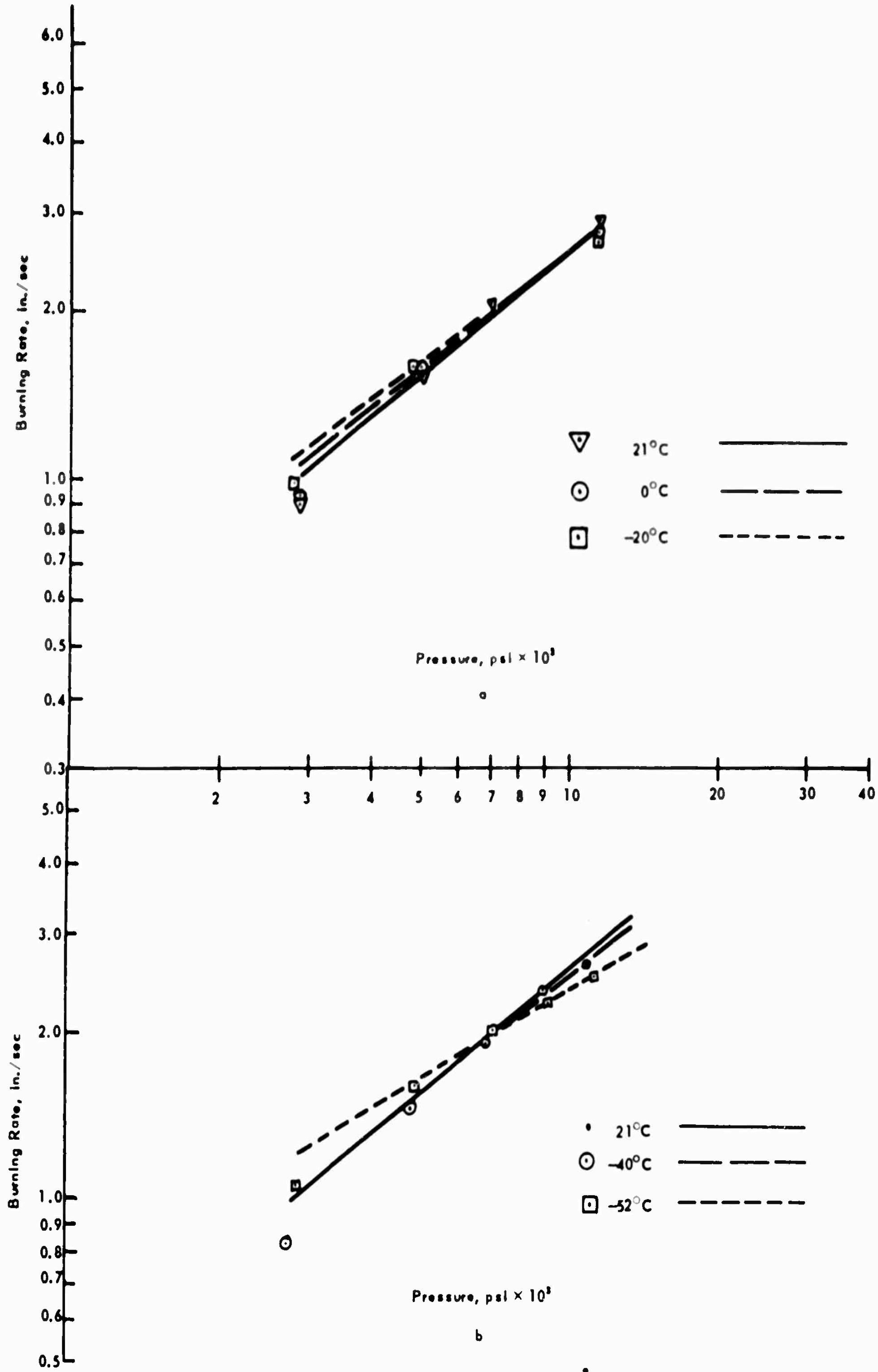

Fig 8 Burning rate vs pressure. M-2 propellant, HPC-18891. 0.1Δ

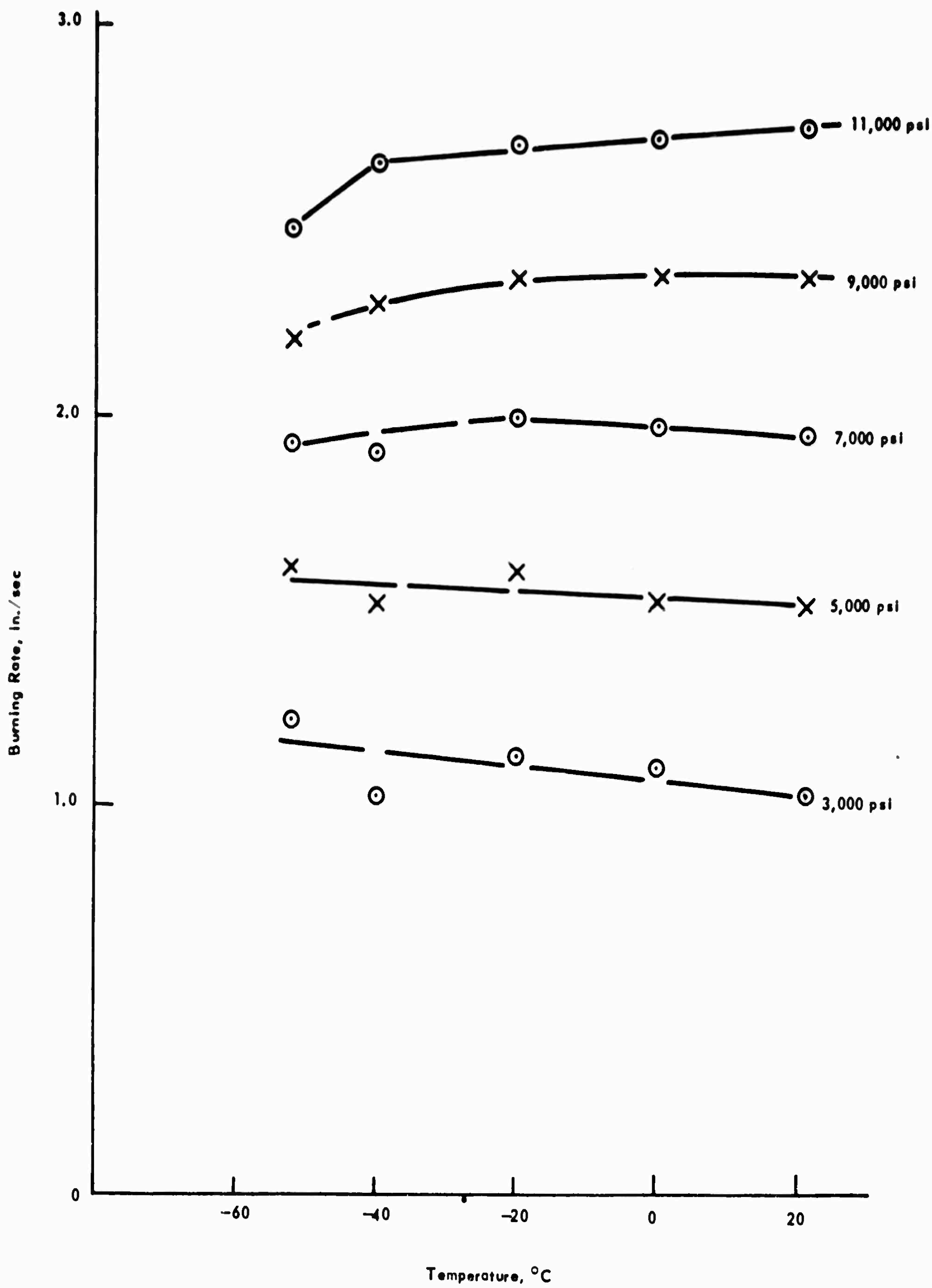

Fig 9 Burning rate vs temperature. M-2 propellant, HPC-18891

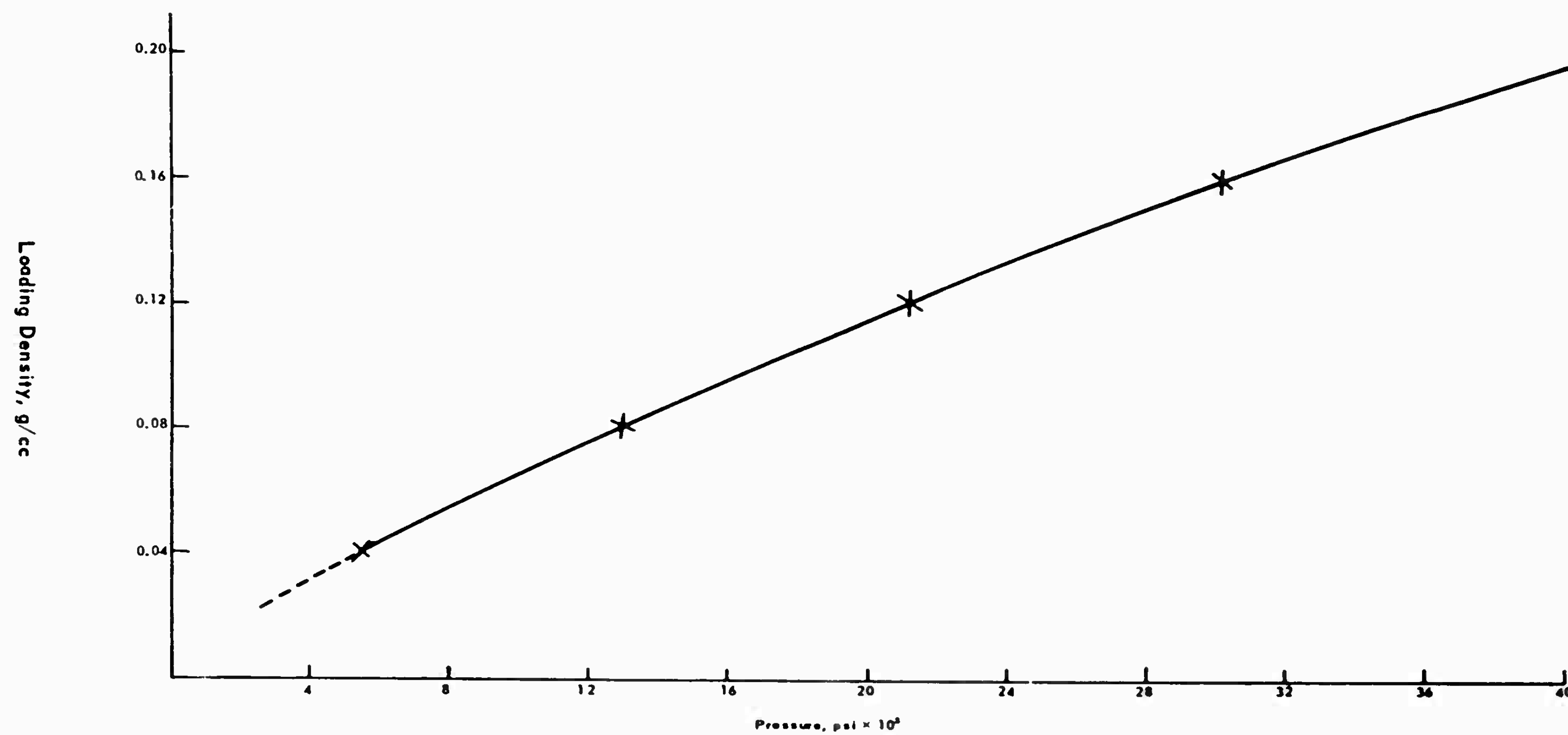

Fig 10 Loading density vs pressure. M-2 propellant, HPC-18891

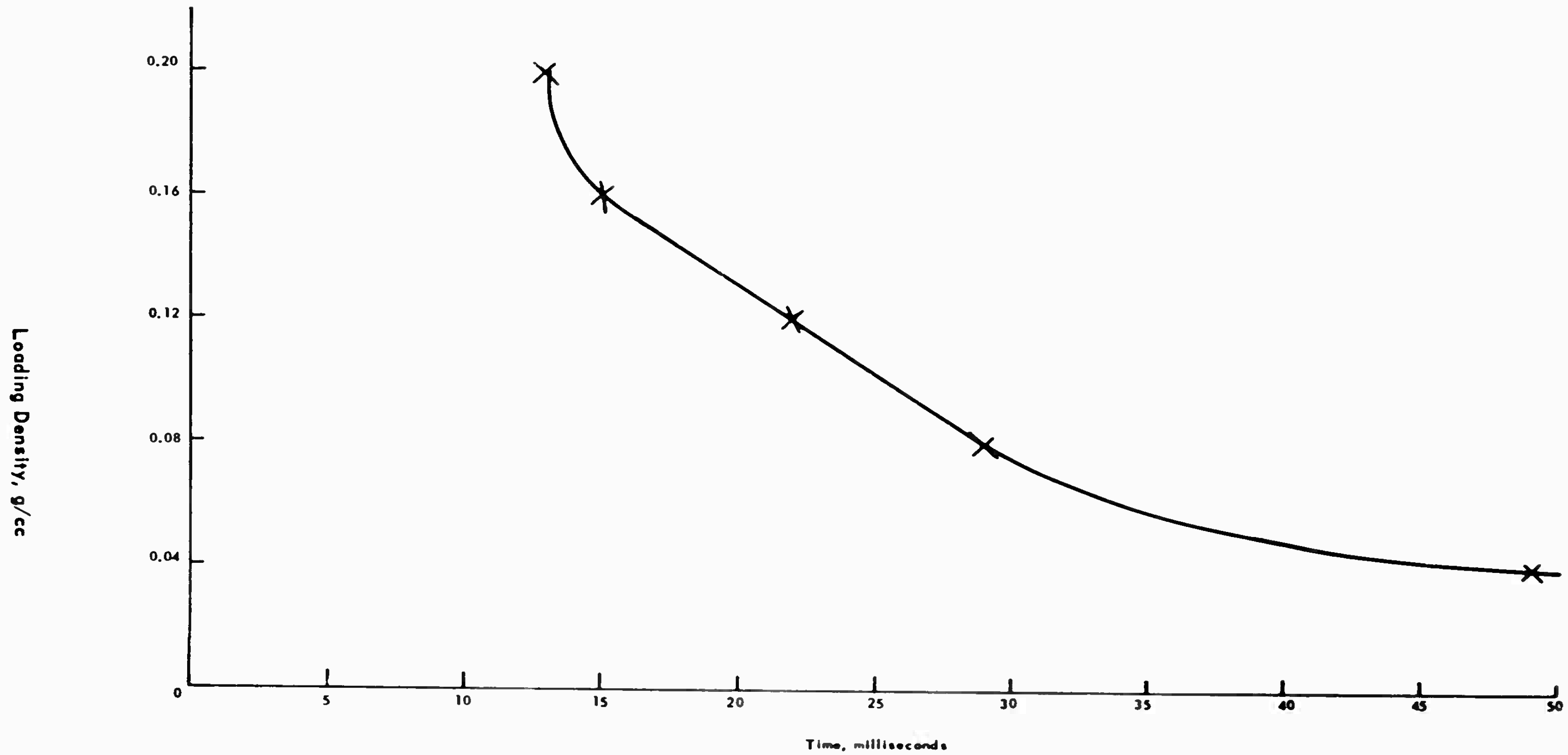

Fig 11 Loading density vs time of burning. M-2 propellant, HPC-18891

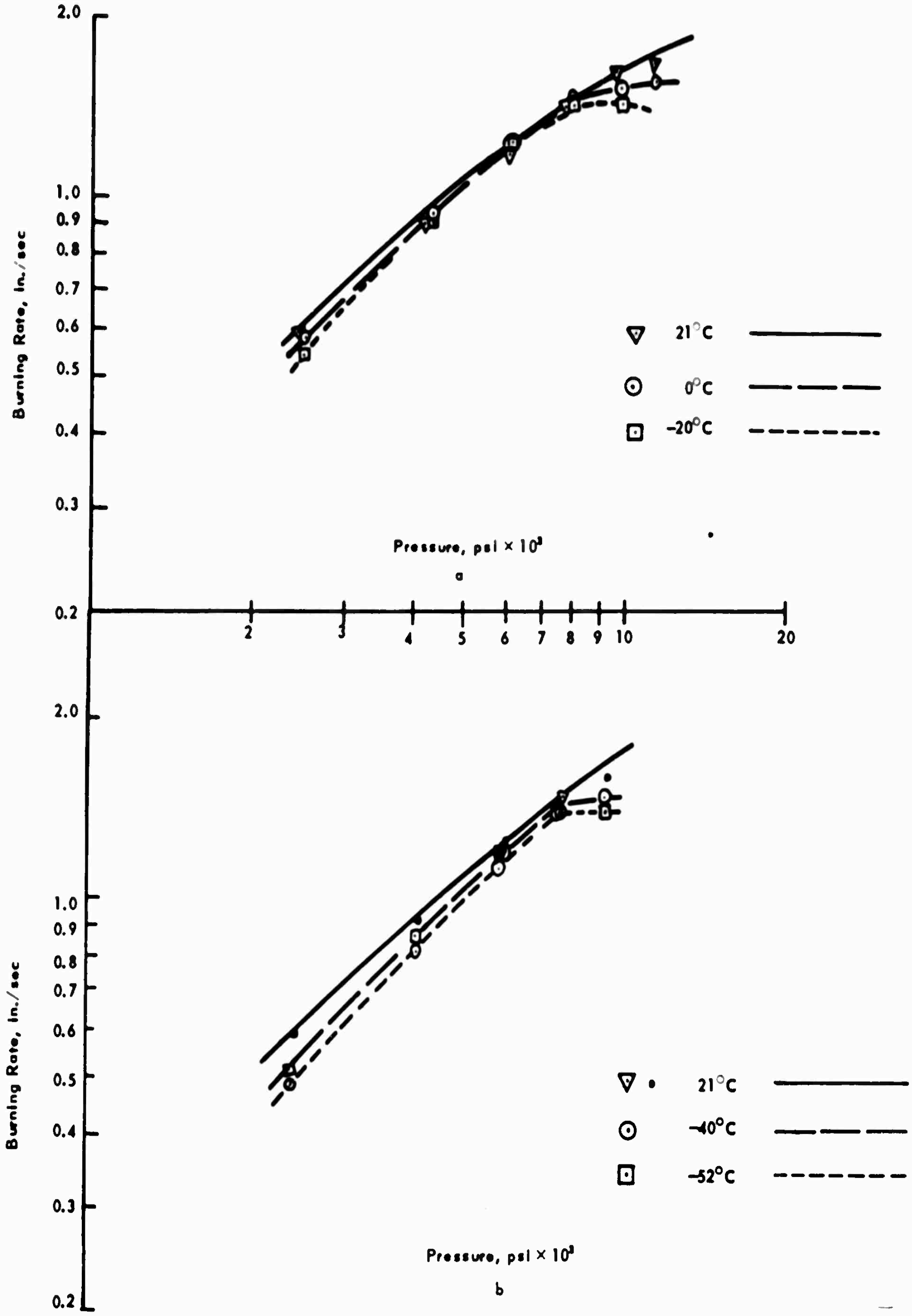

Fig 12 Burning rate vs pressure. M-6 propellant, PAE-21378. 0.1Δ

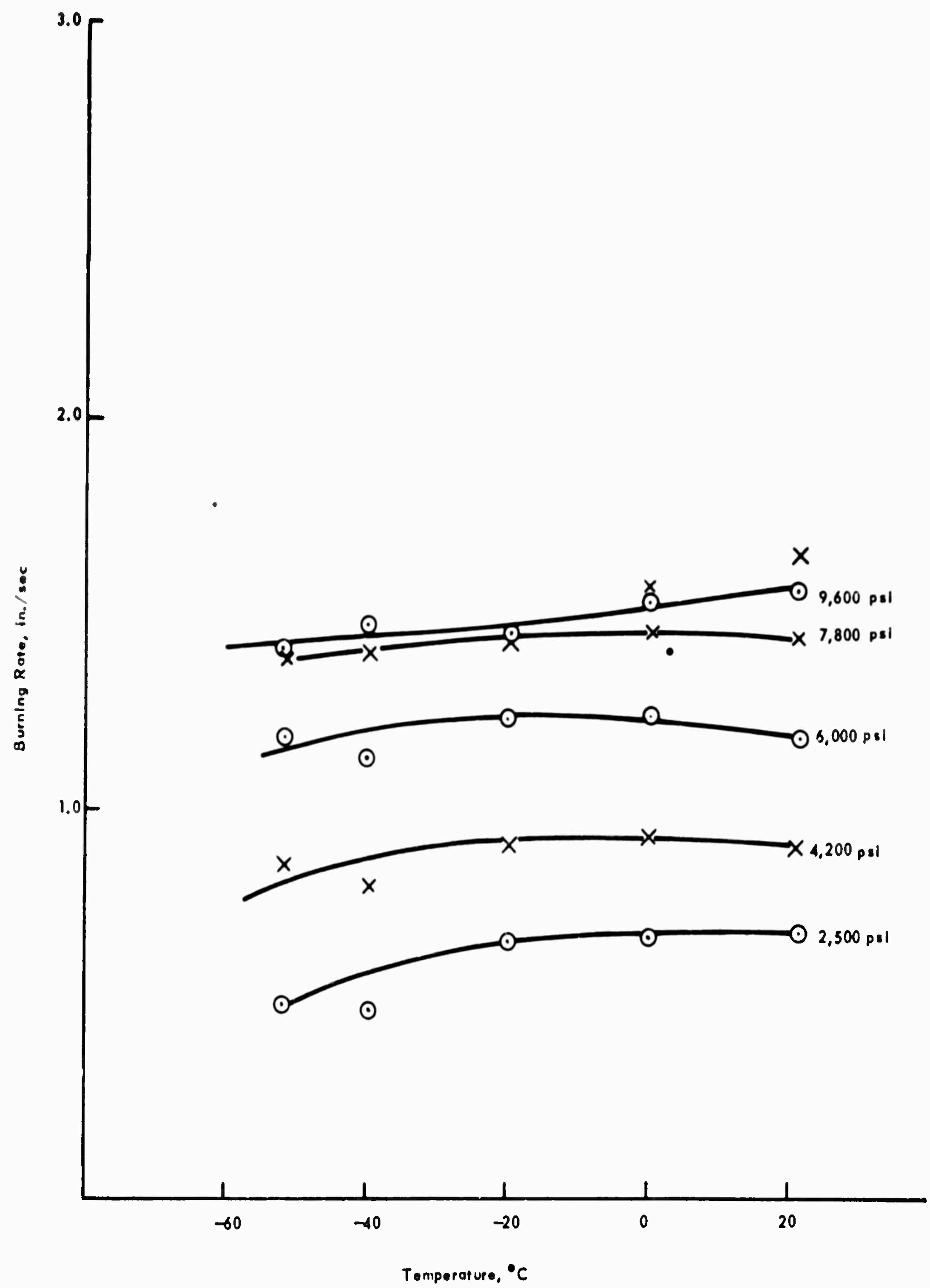

Fig 13 Burning rate vs temperature. M-6 propellant, PAE-21378

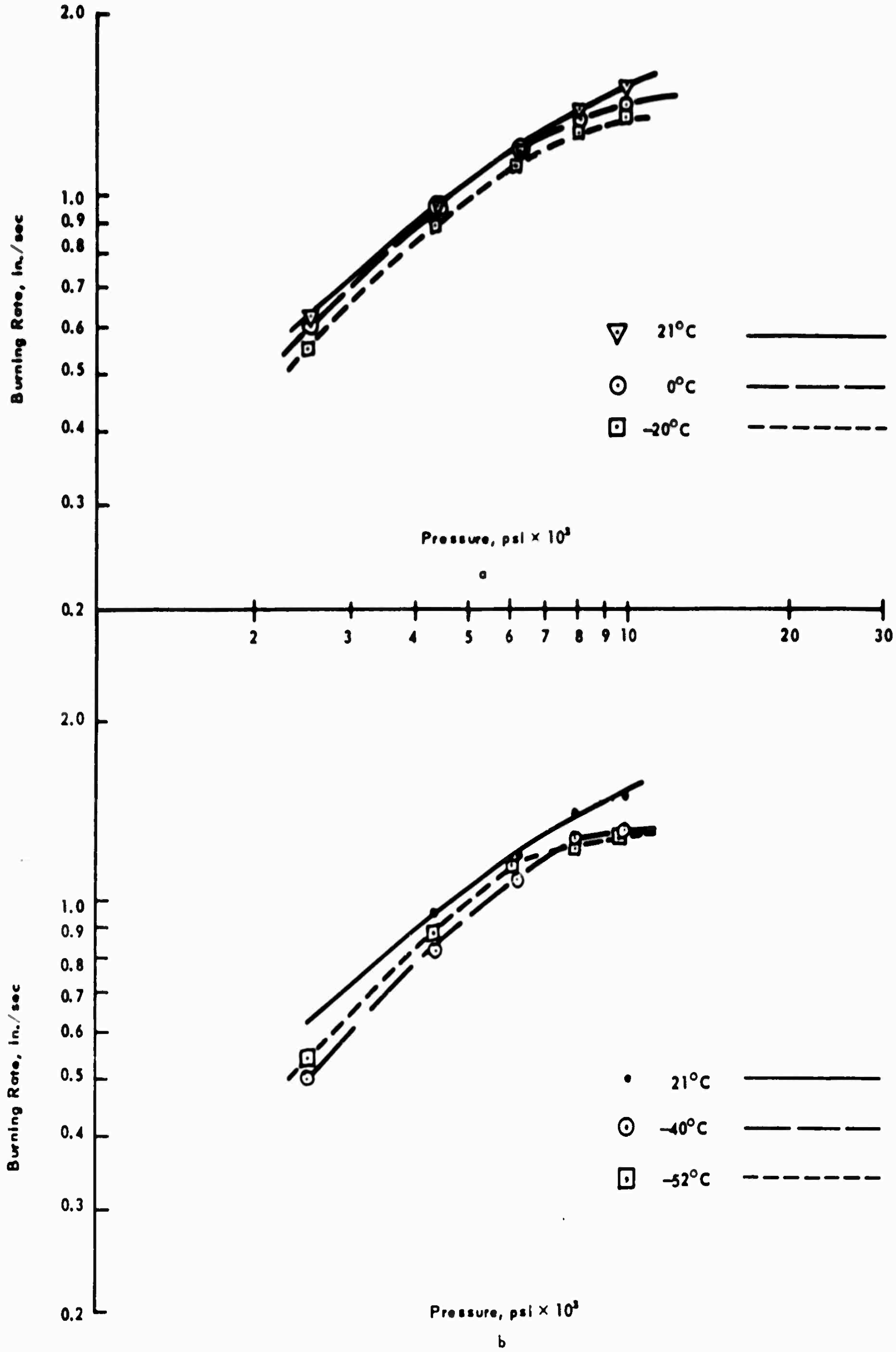

Fig 14 Burning rate vs pressure. M-6 propellant, PAE-19121. 0.1Δ

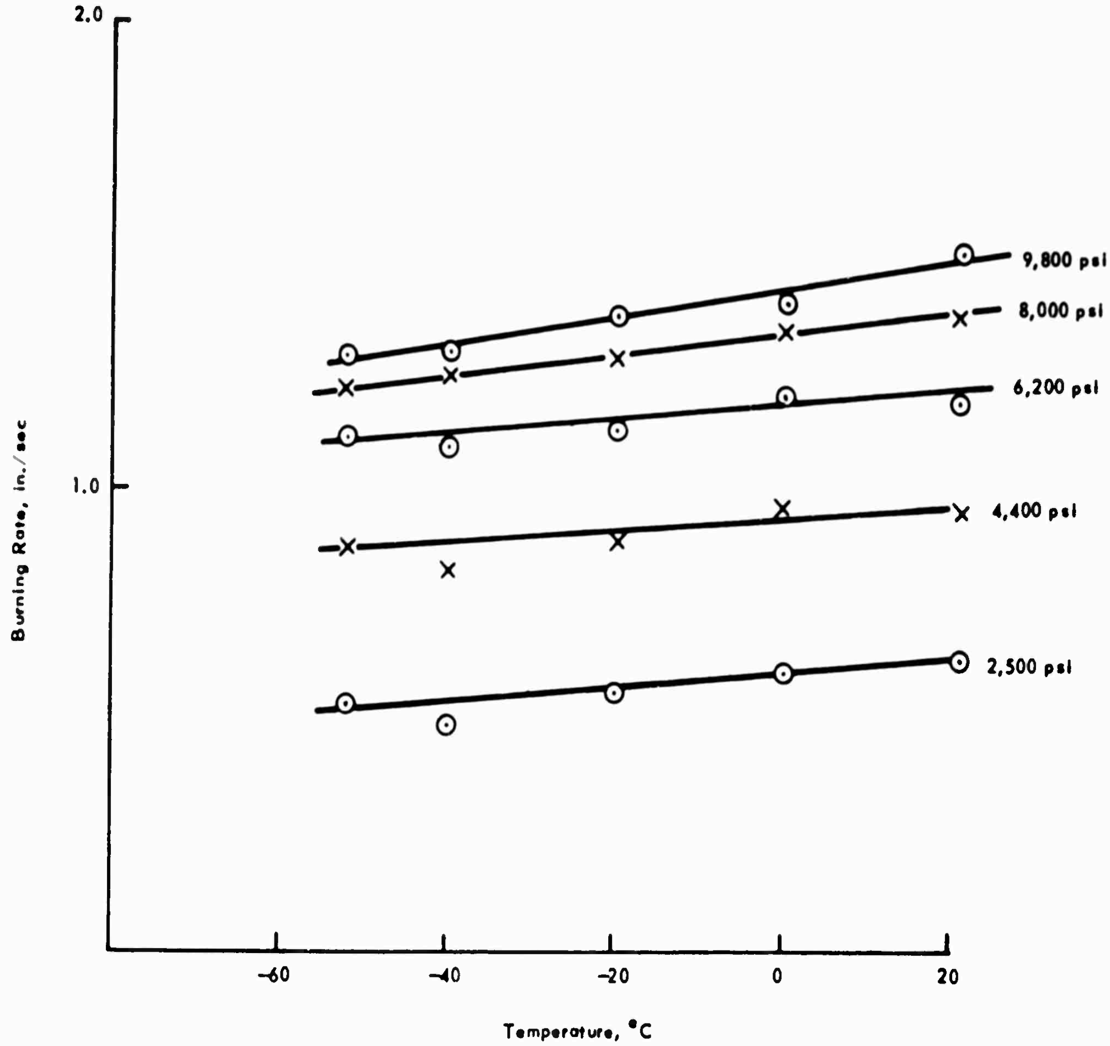

Fig 15 Burning rate vs temperature. M-6 propellant, PAE-19121

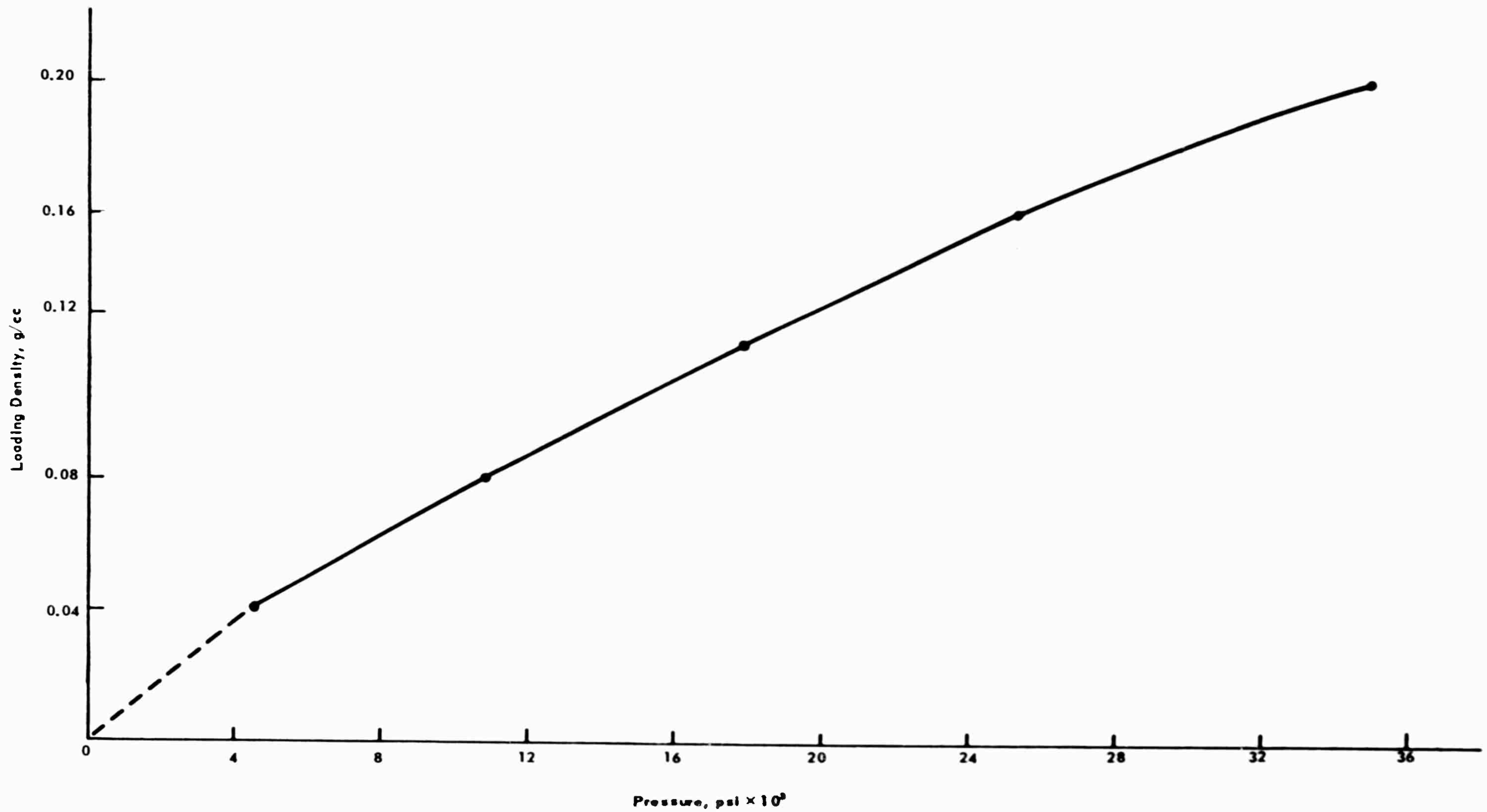

Fig 16 Loading density vs pressure. M-6 propellant, PAE-19121

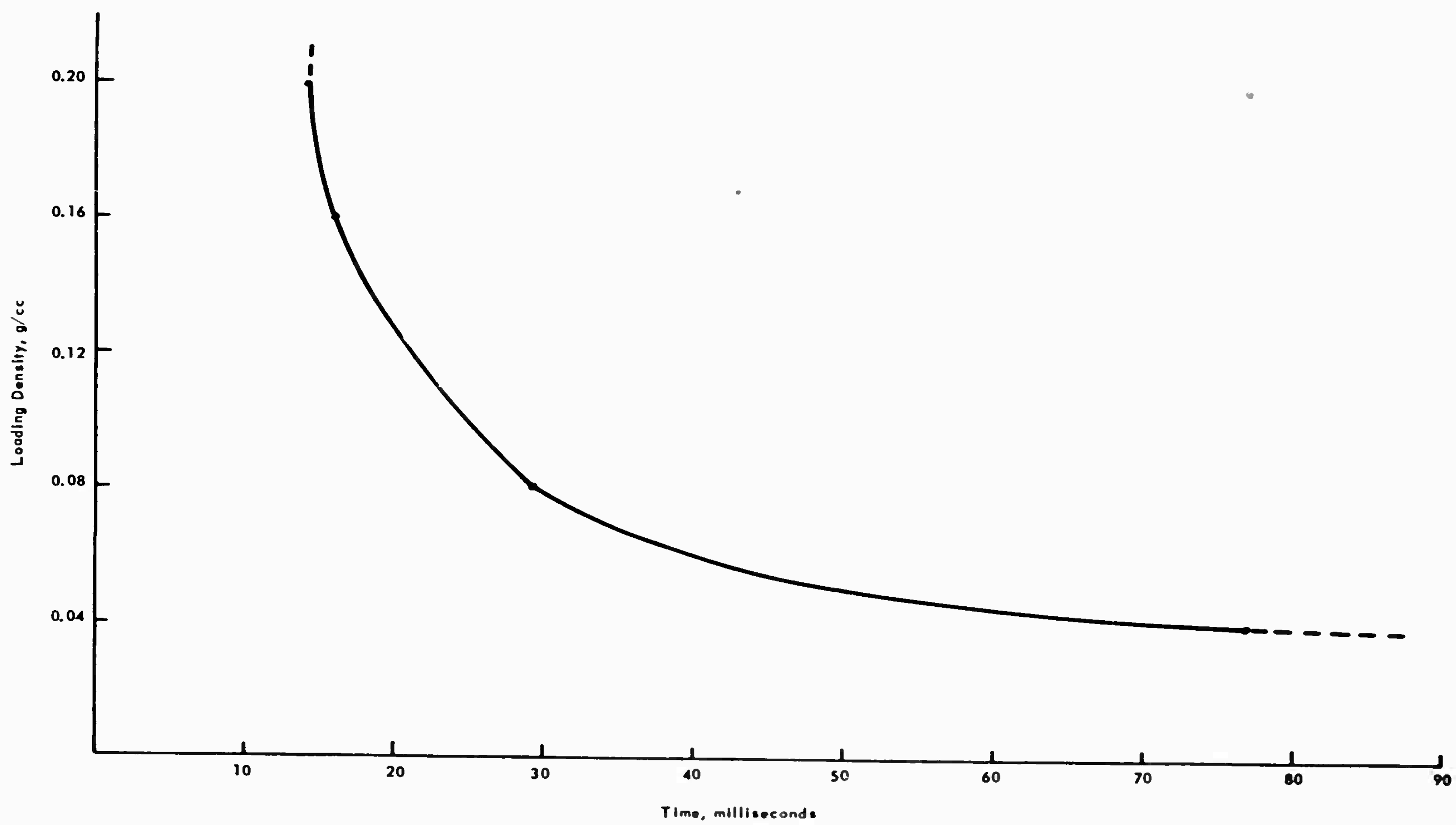

Fig 17 Loading density vs time of burning. M-6 propellant, PAE-19121

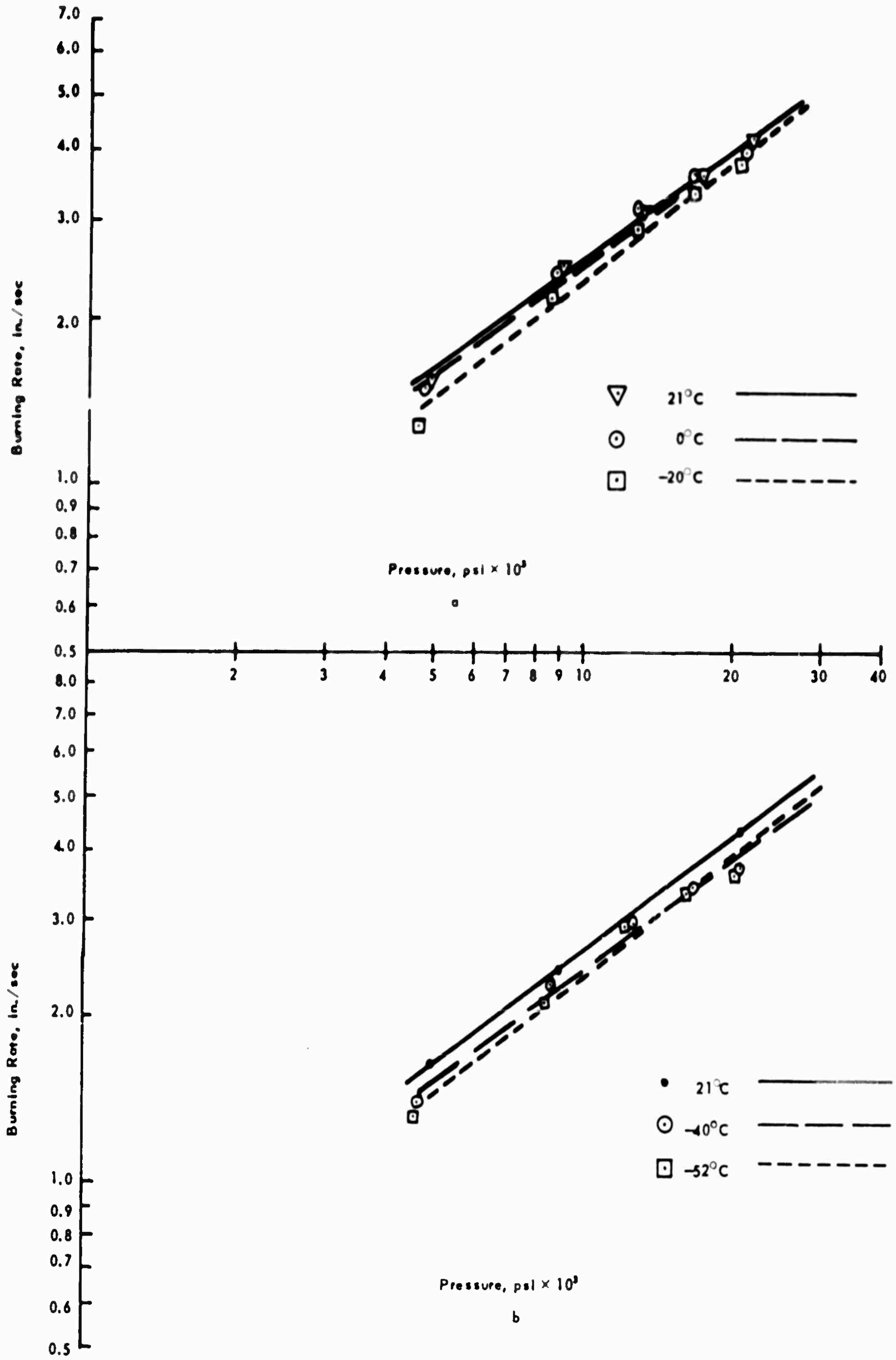

Fig 18 Burning rate vs pressure. M-6 propellant, IND-8799. 0.2Δ

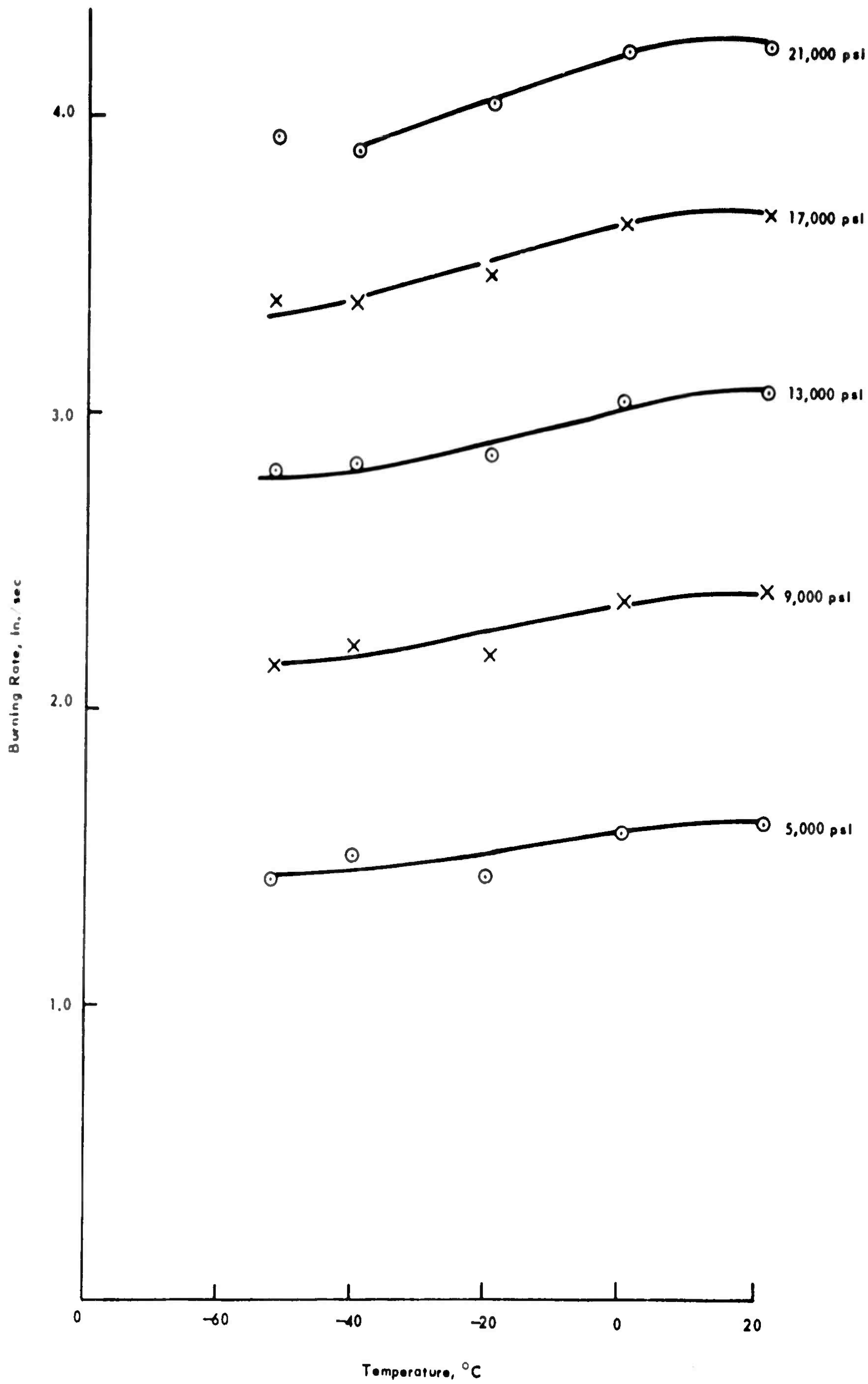

Fig 19 Burning rate vs temperature. M-6 propellant, IND-8799

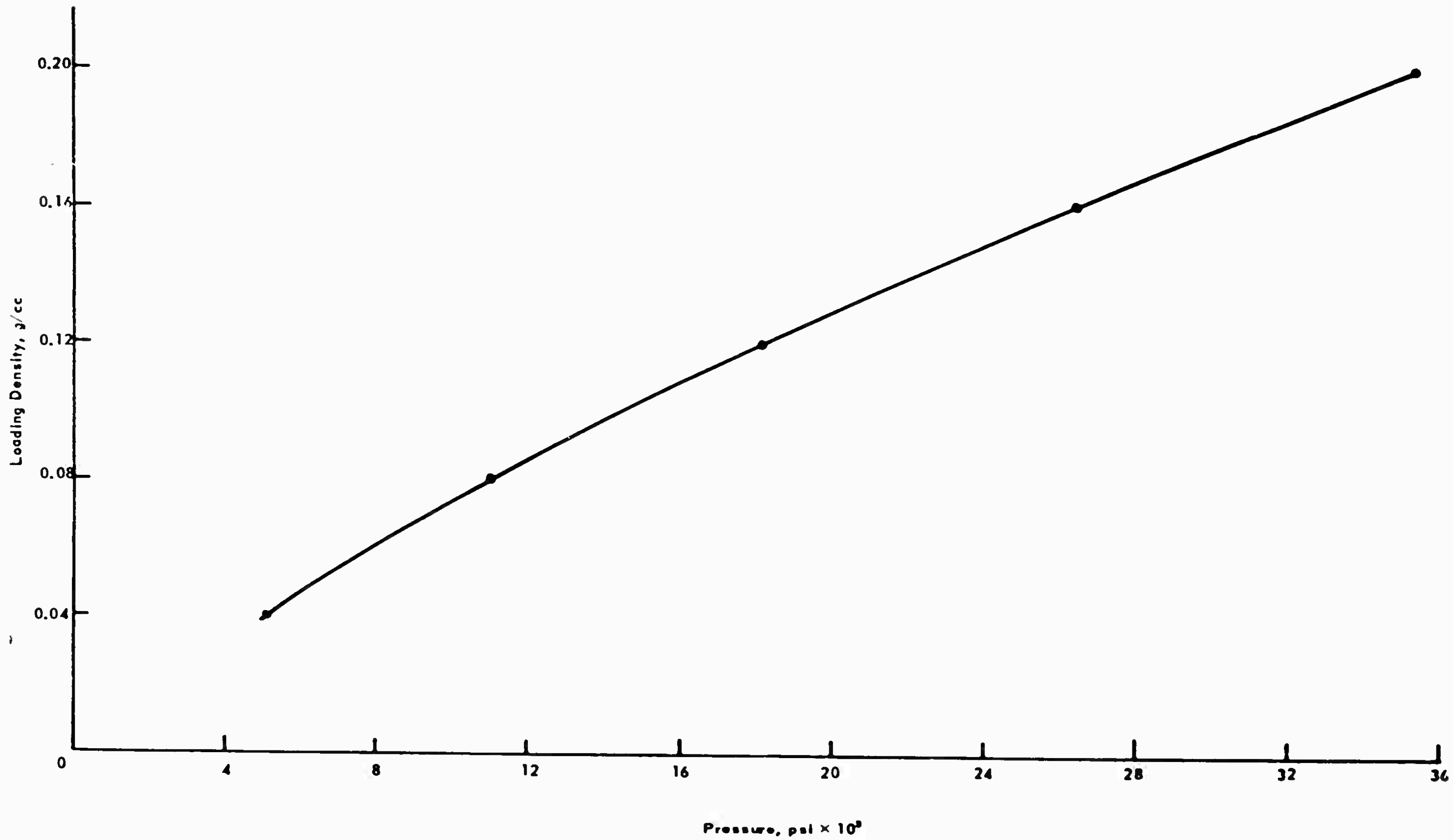

Fig 20 Loading density vs pressure. M-6 propellant, IND-8799

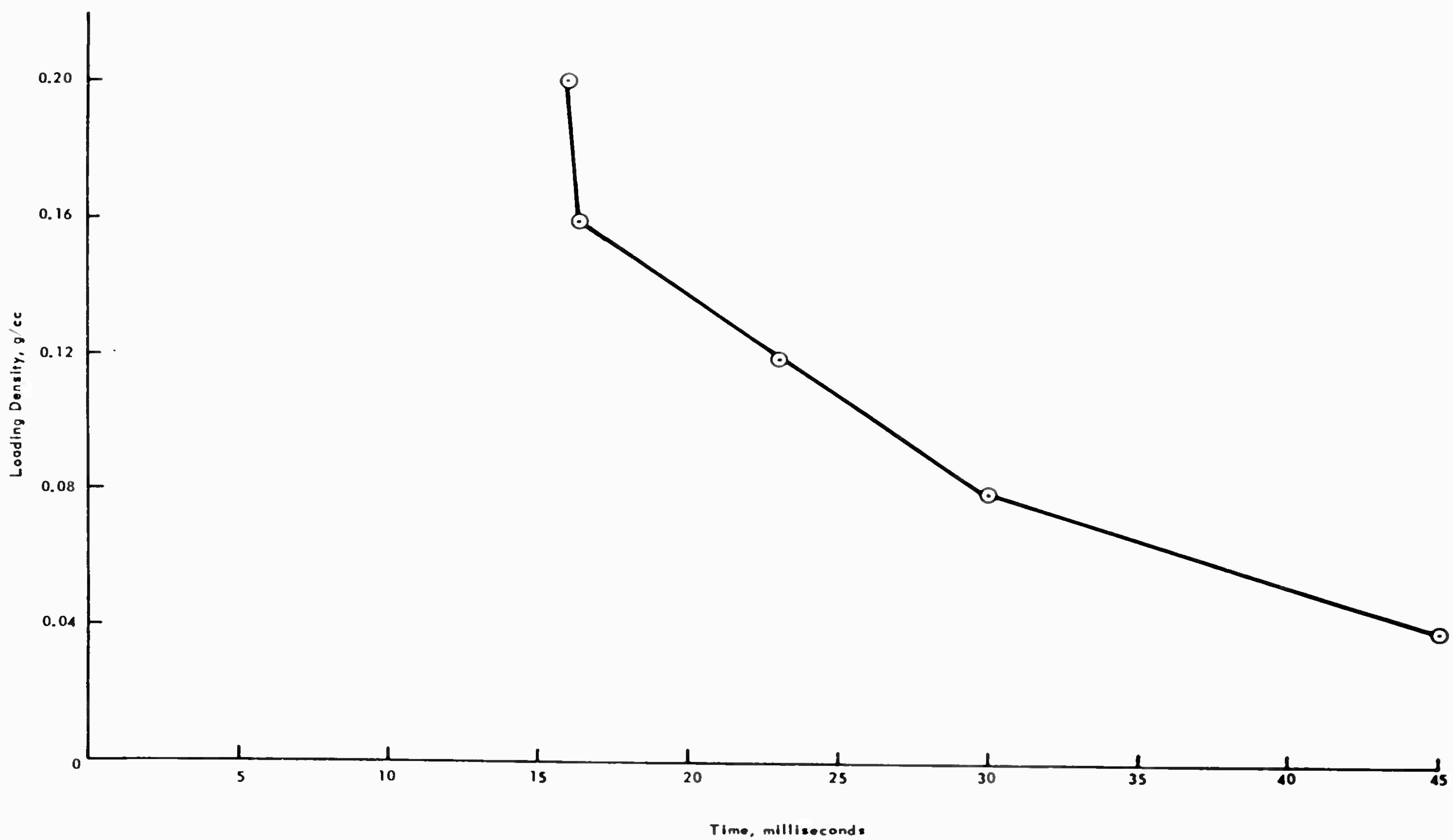

Fig 21 Loading density vs time of burning. M-6 propellant, IND-8799

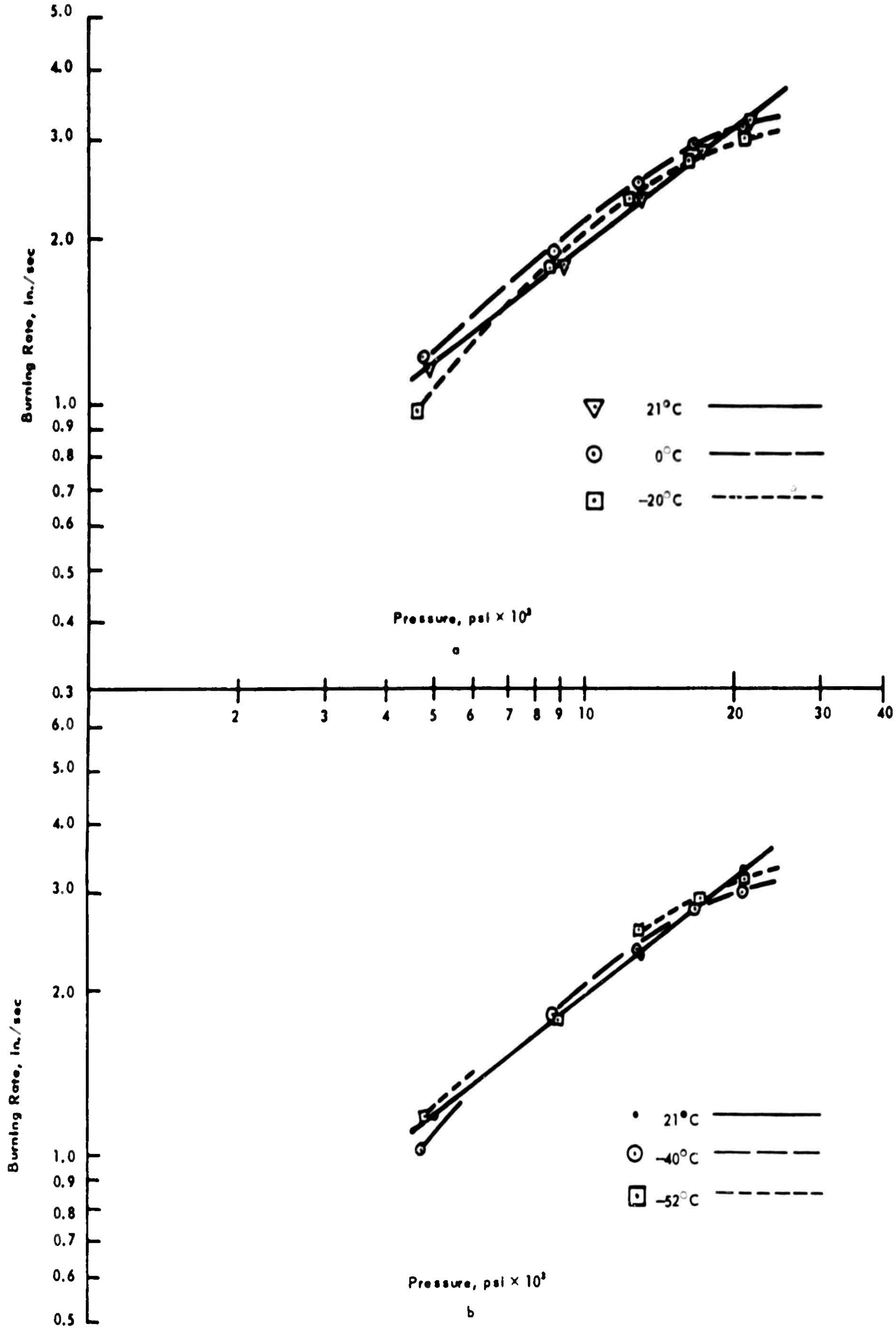

Fig 22 Burning rate vs pressure. M-6 propellant, IOW-6667. 0.2Δ

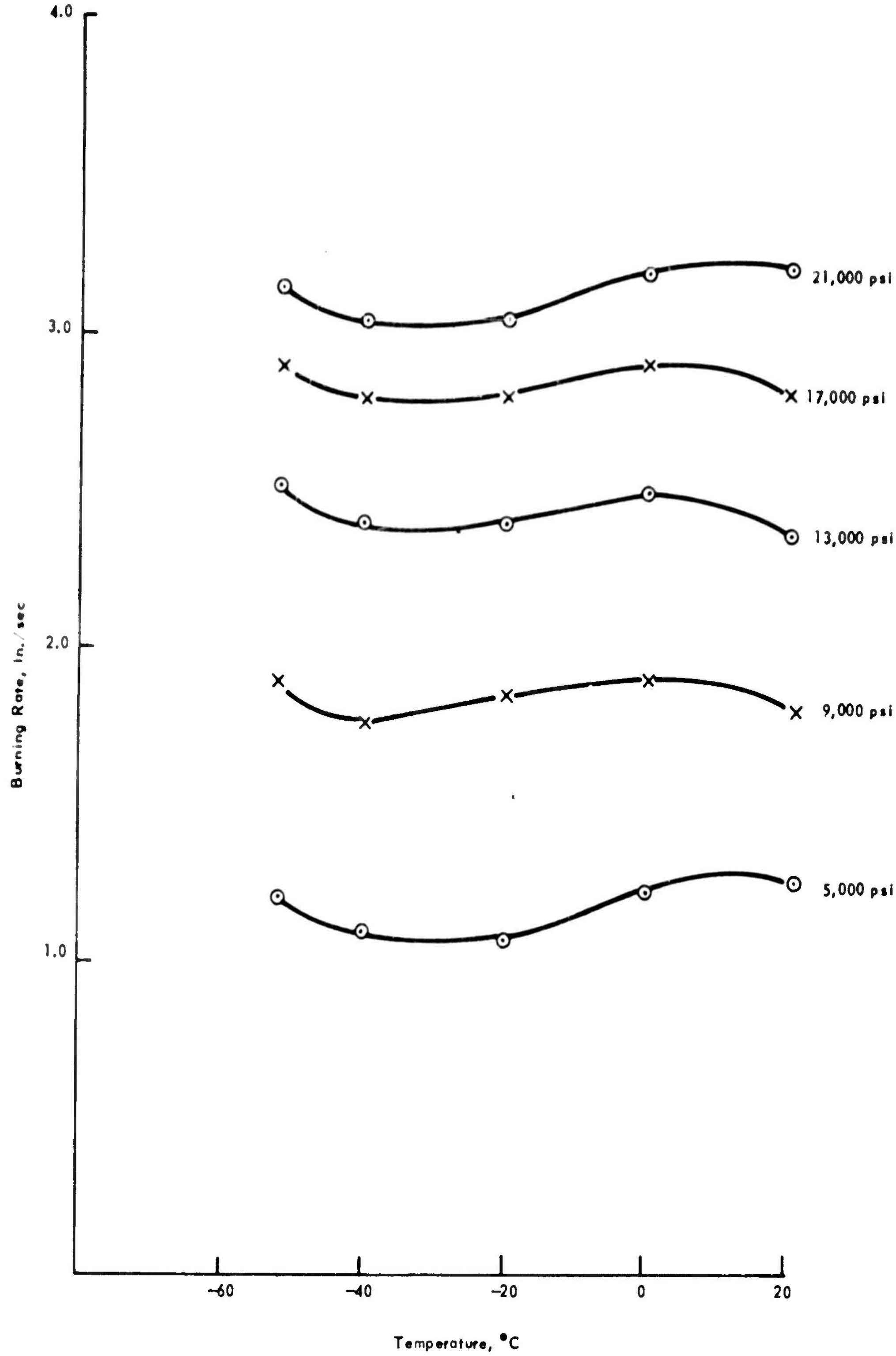

Fig 23 Burning rate vs temperature. M-6 propellant, IOW-6667

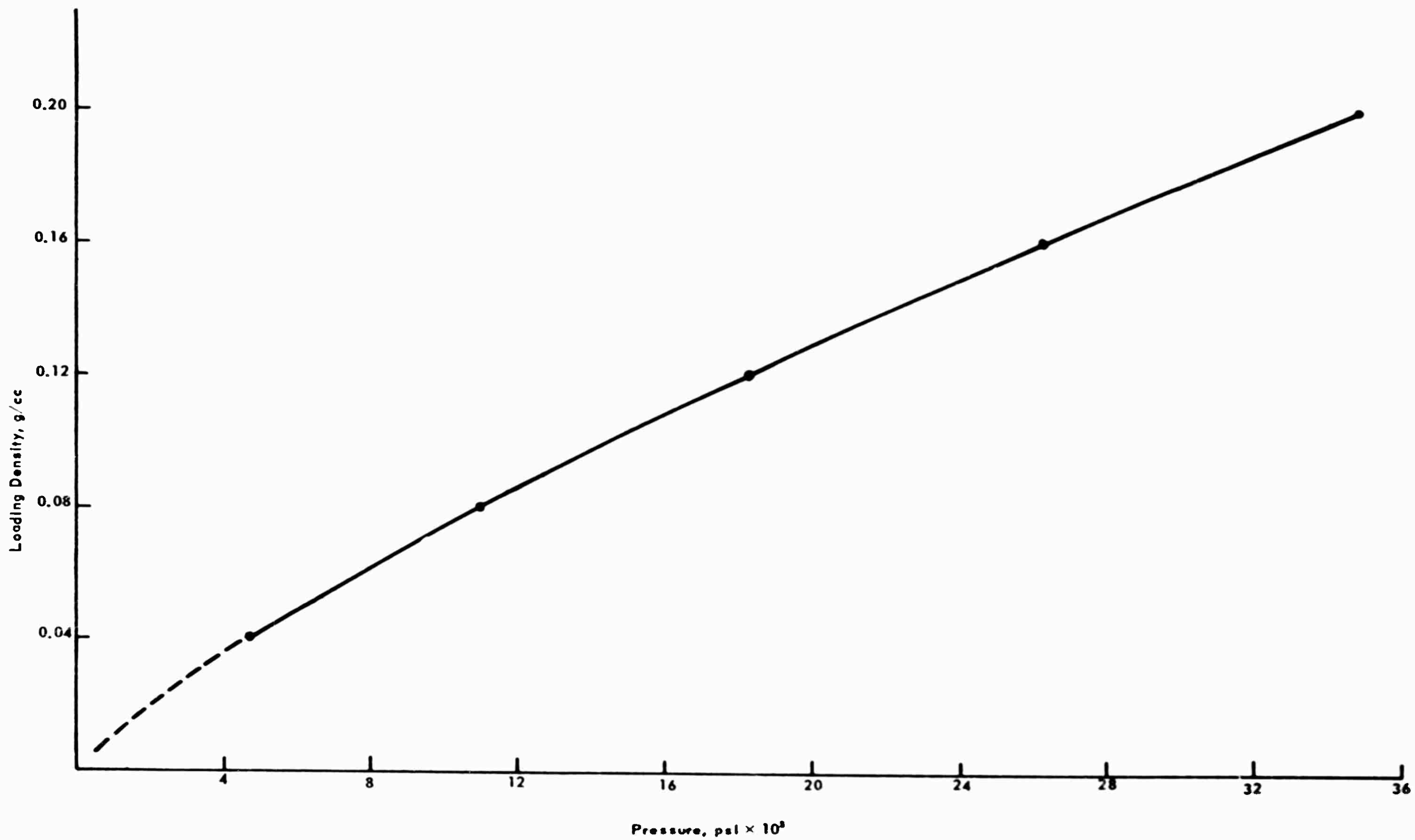

Fig 24 Loading density vs pressure. M-6 propellant, IOW-6667

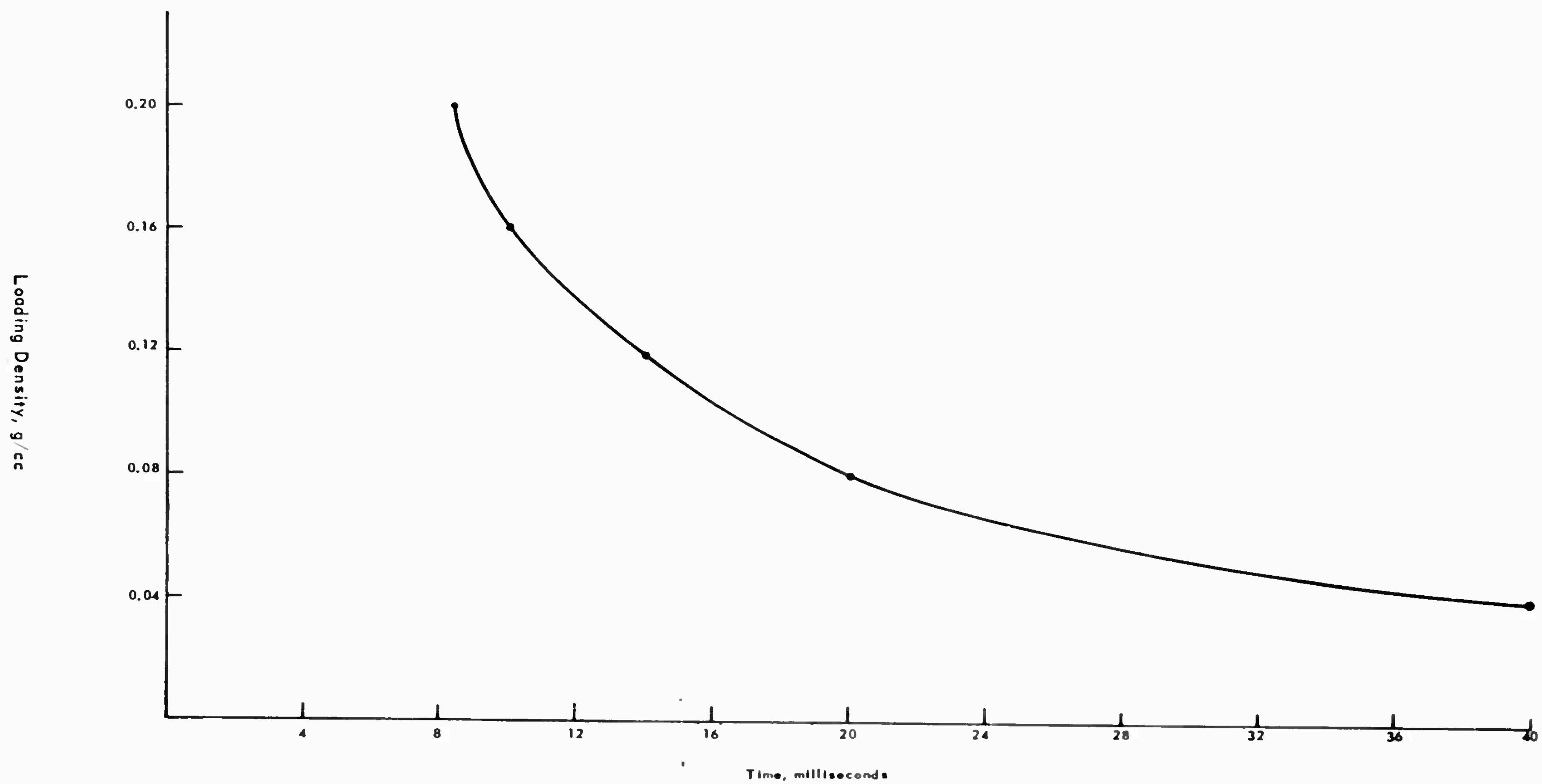

Fig 25 Loading density vs time of burning. M-6 propellant, IOW-6667

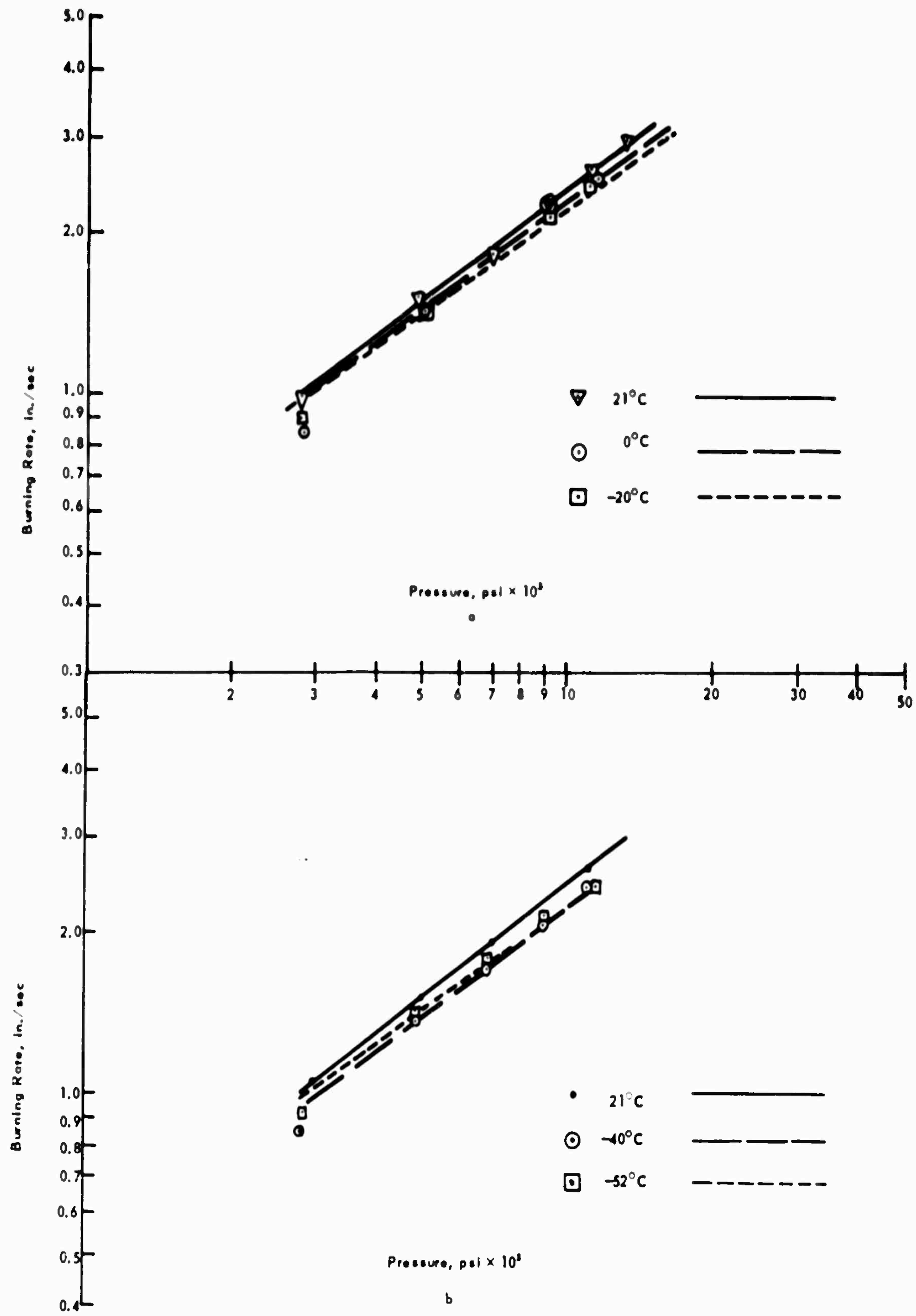

Fig 26 Burning rate vs pressure. M-10 propellant, PA-30187. 0.1Δ

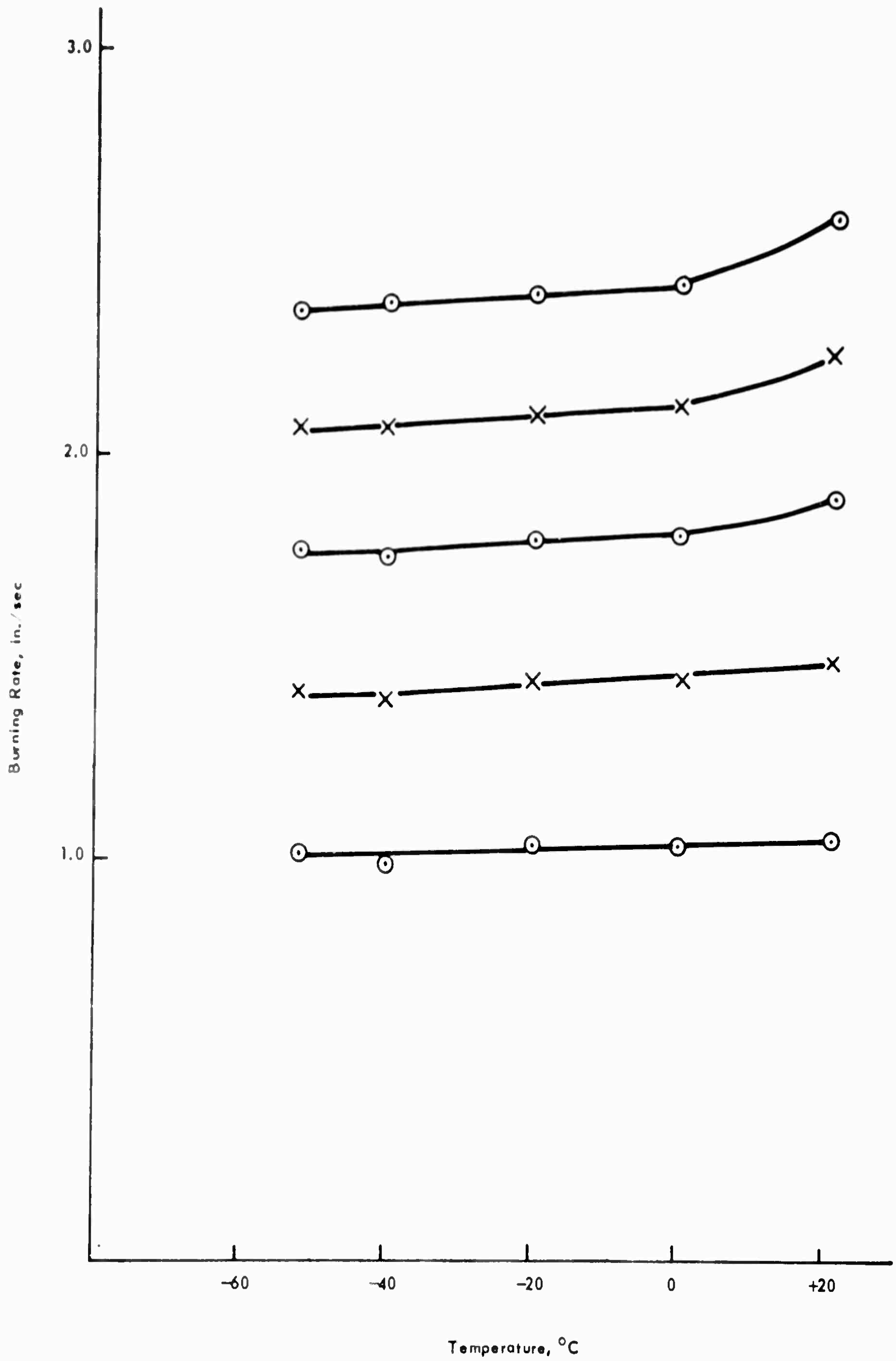

Fig 27 Burning rate vs temperature. M-10 propellant, PA-30187

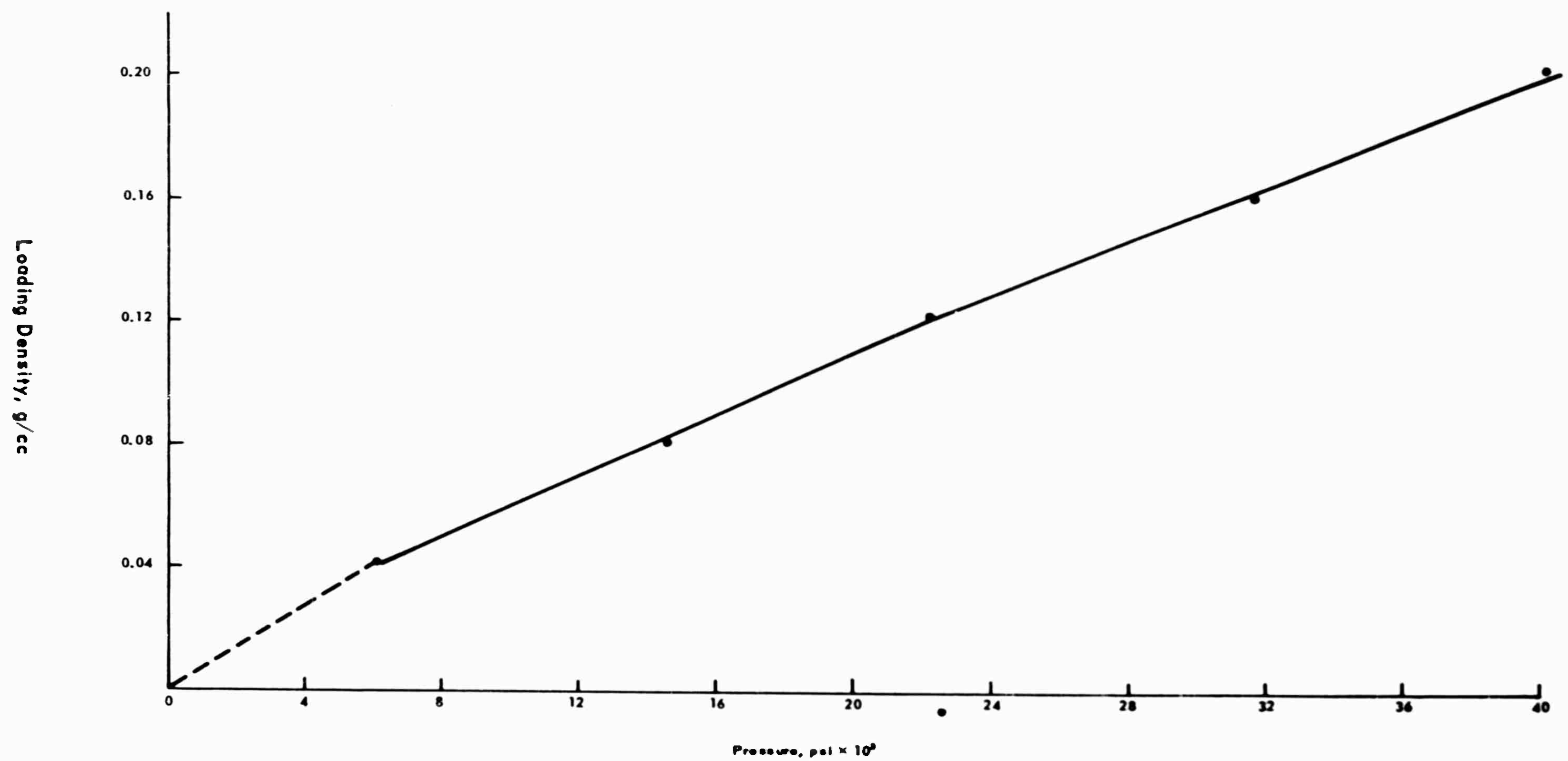

Fig 28 Loading density vs pressure. M-10 propellant, PA-30187

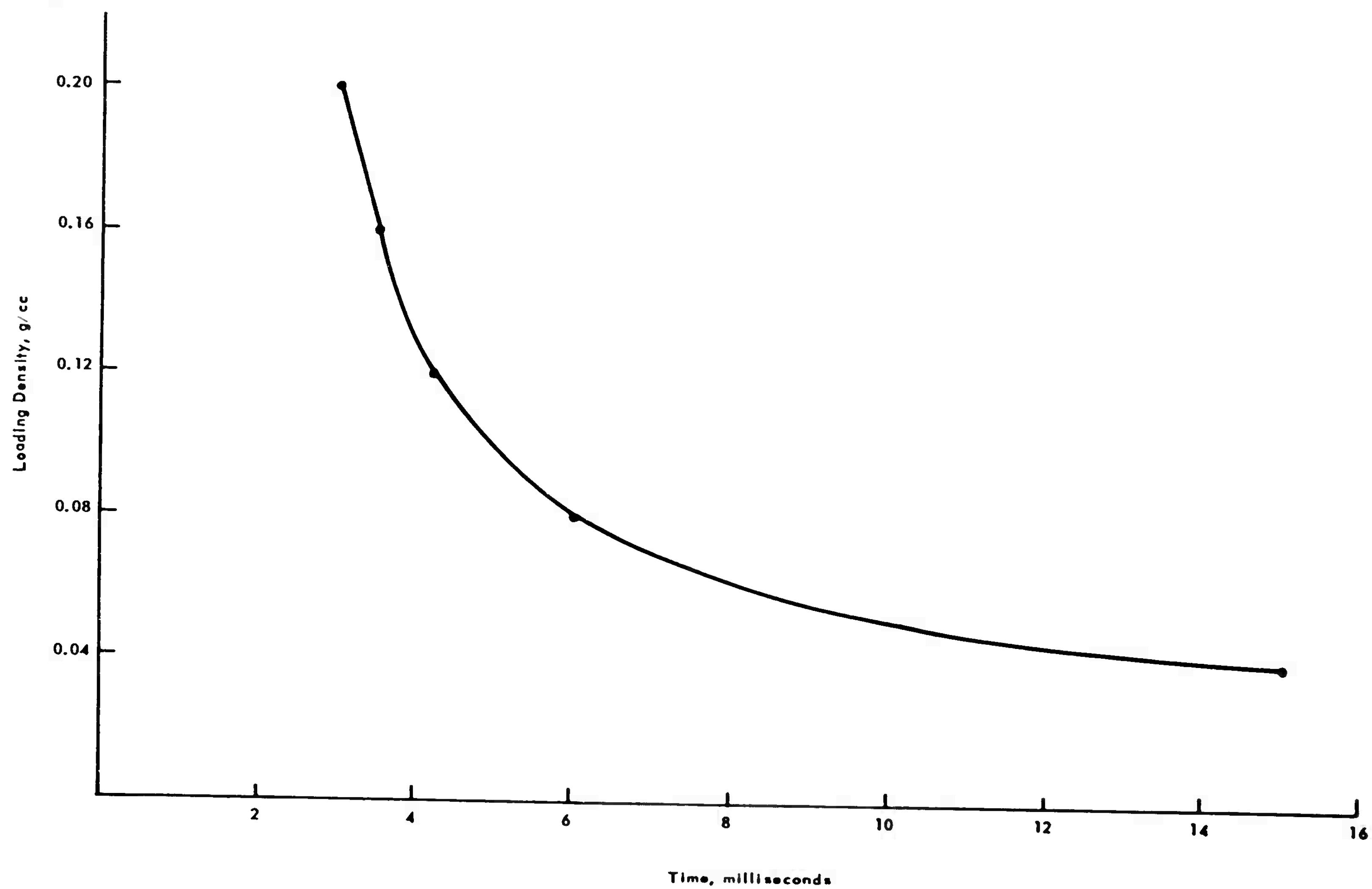

Fig 29 Loading density vs time of burning. M-10 propellant, PA-30187

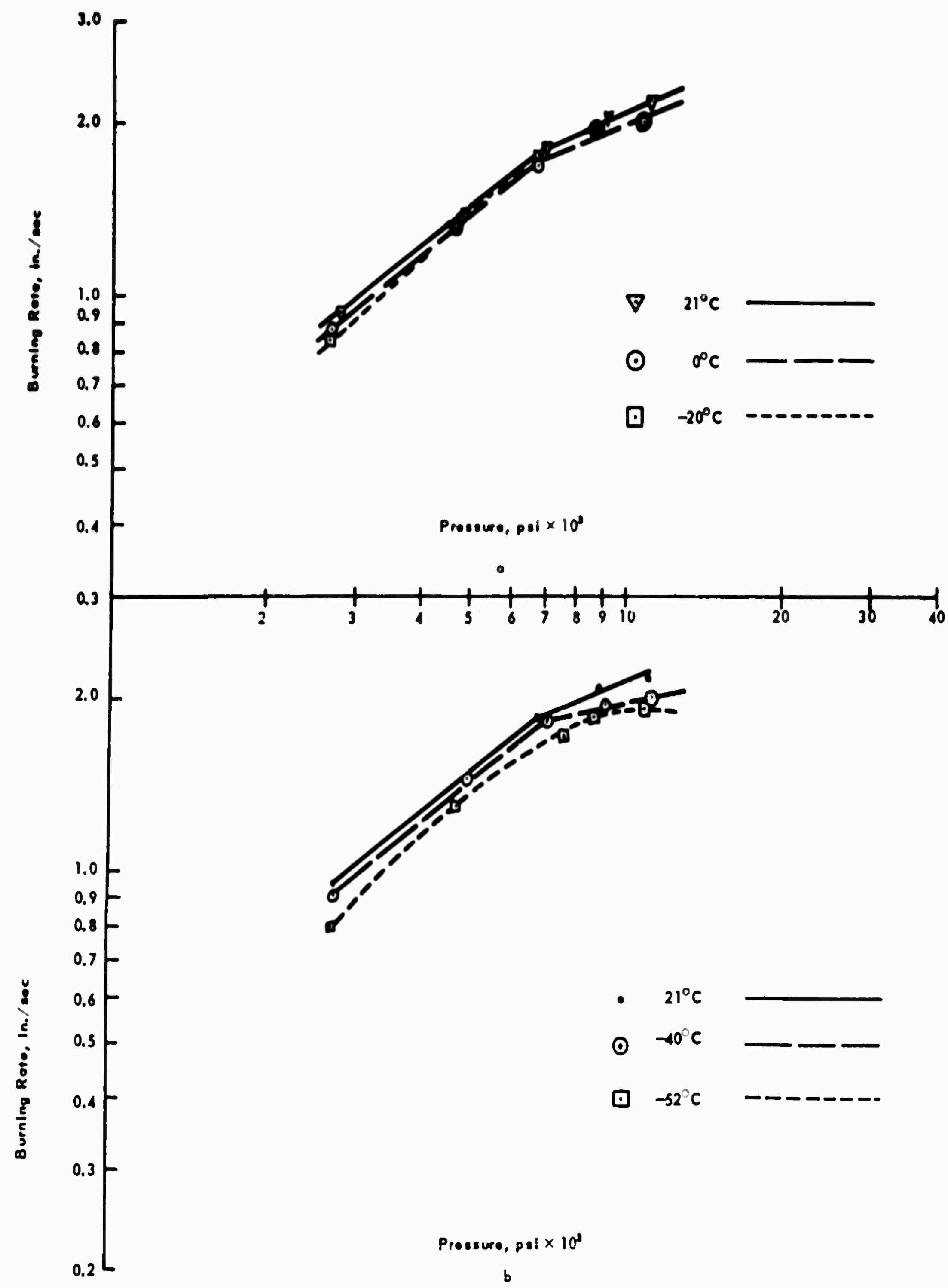

Fig 30 Burning rate vs pressure. M-10 propellant, RAD-35626. 0.1Δ

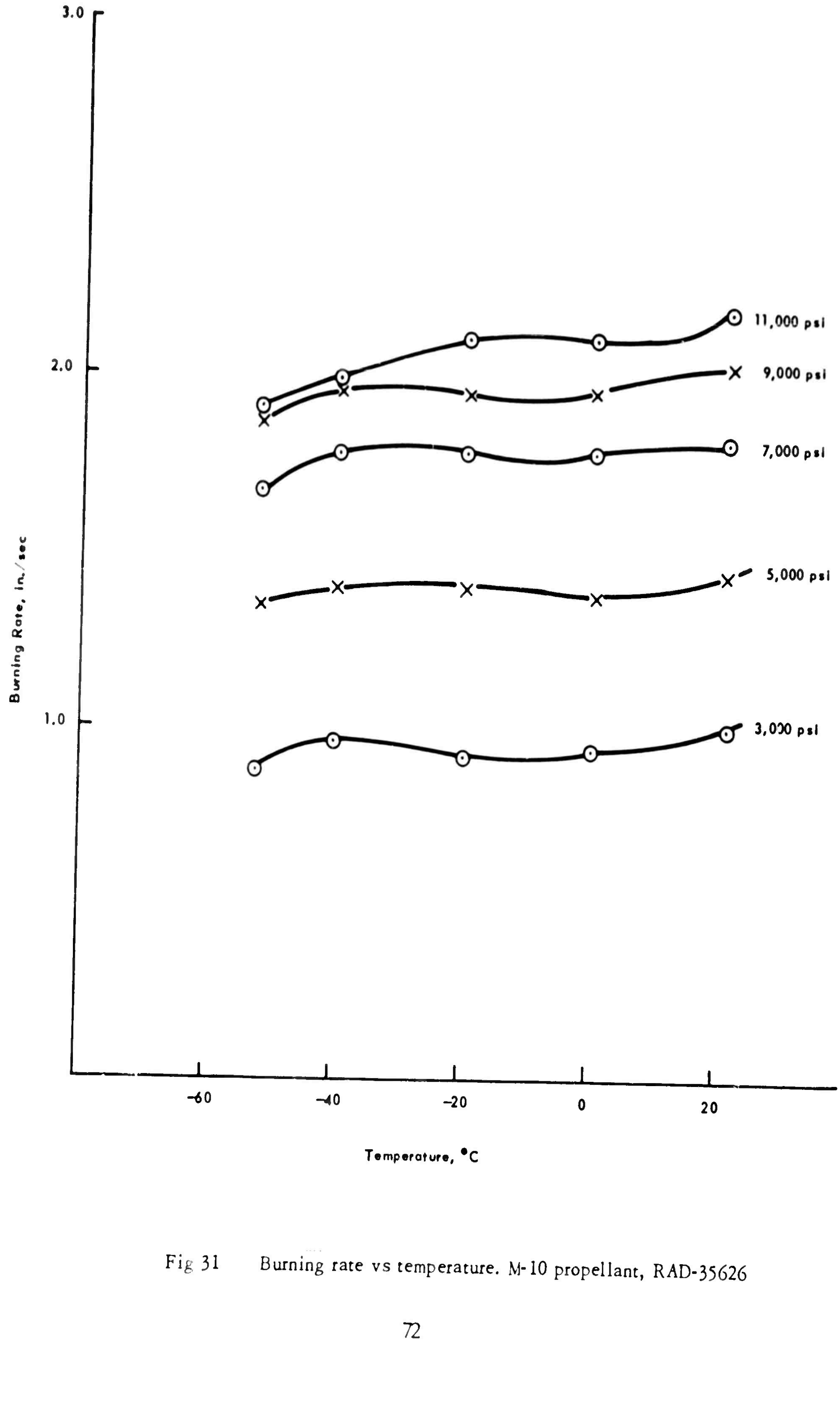

Fig 31 Burning rate vs temperature. M-10 propellant, RAD-35626

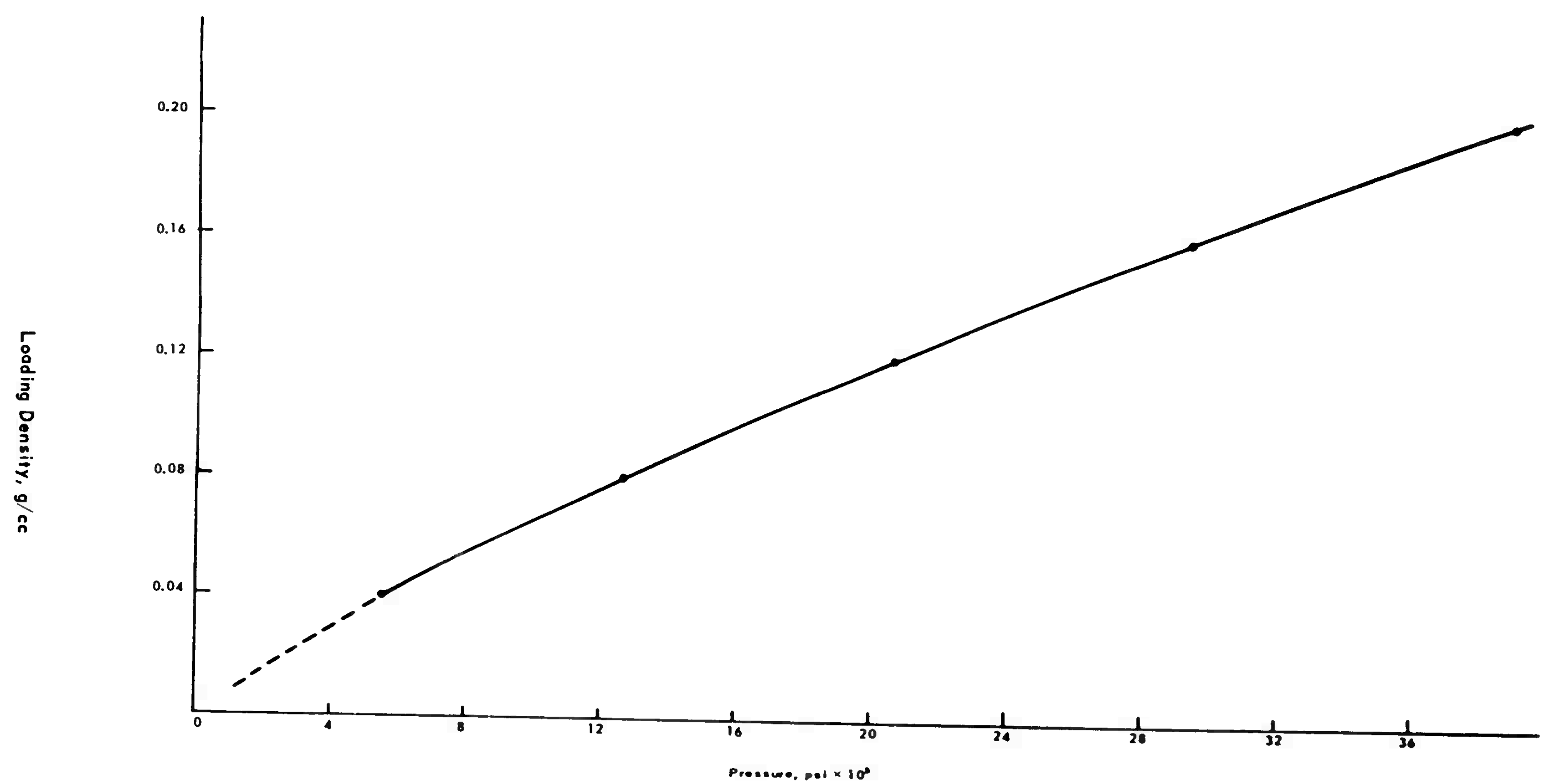

Fig 32 Loading density vs pressure. M-10 propellant, RAD-35626

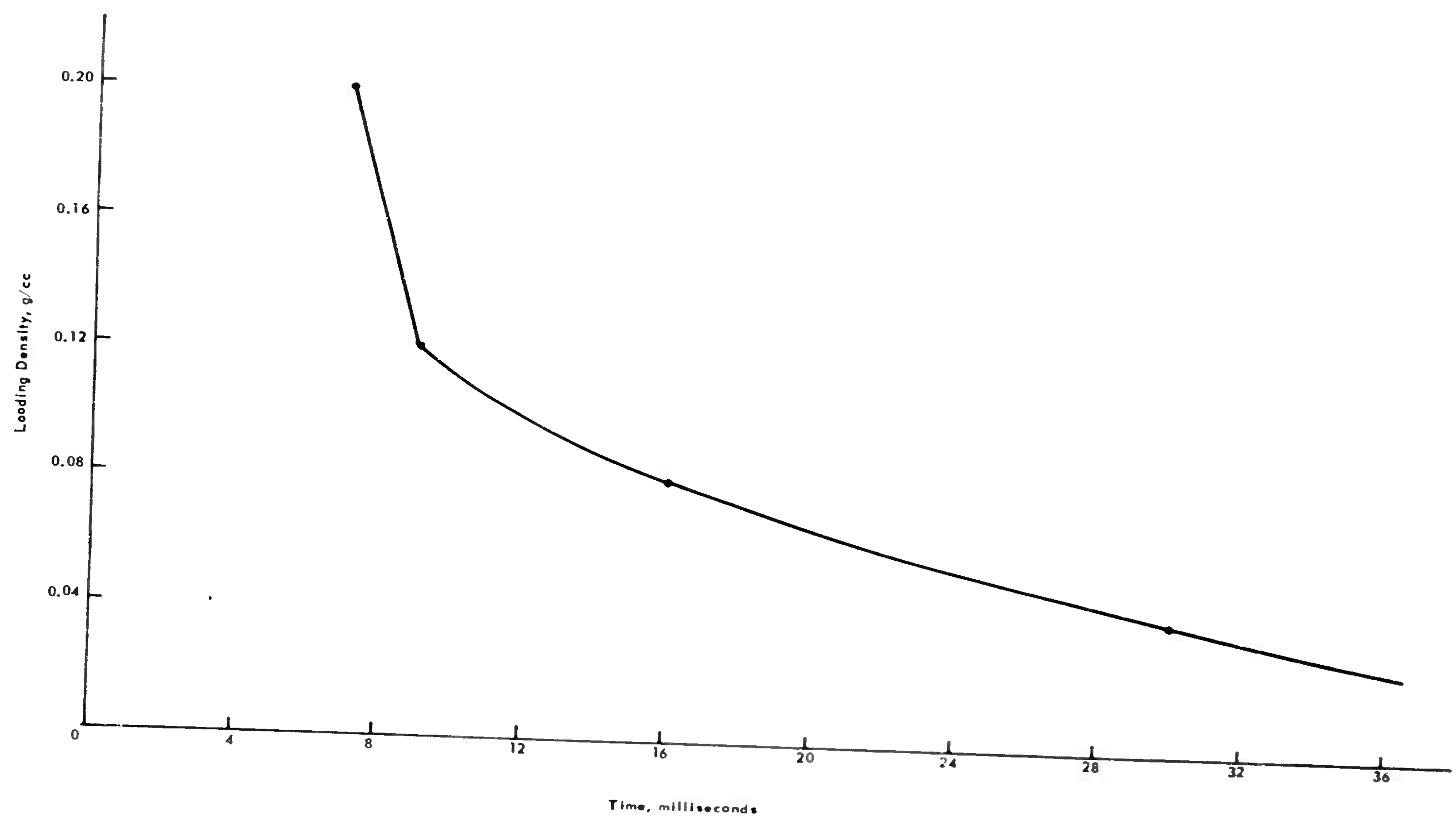

Fig 33 Loading density vs time of burning. M-10 propellant, RAD-35626

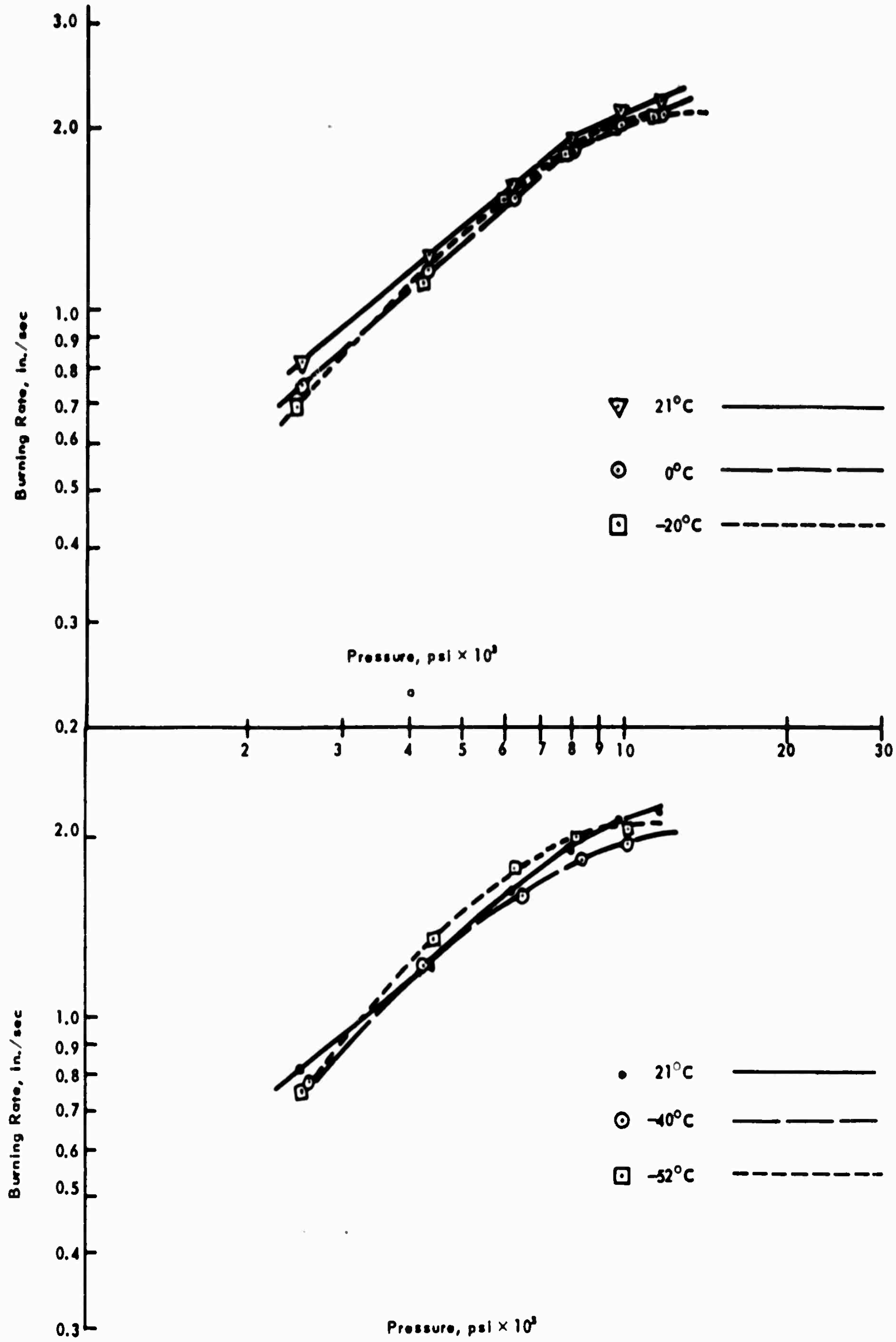

Fig 34 Burning rate vs pressure. M-10 propellant, PAE-30257. 0.1Δ

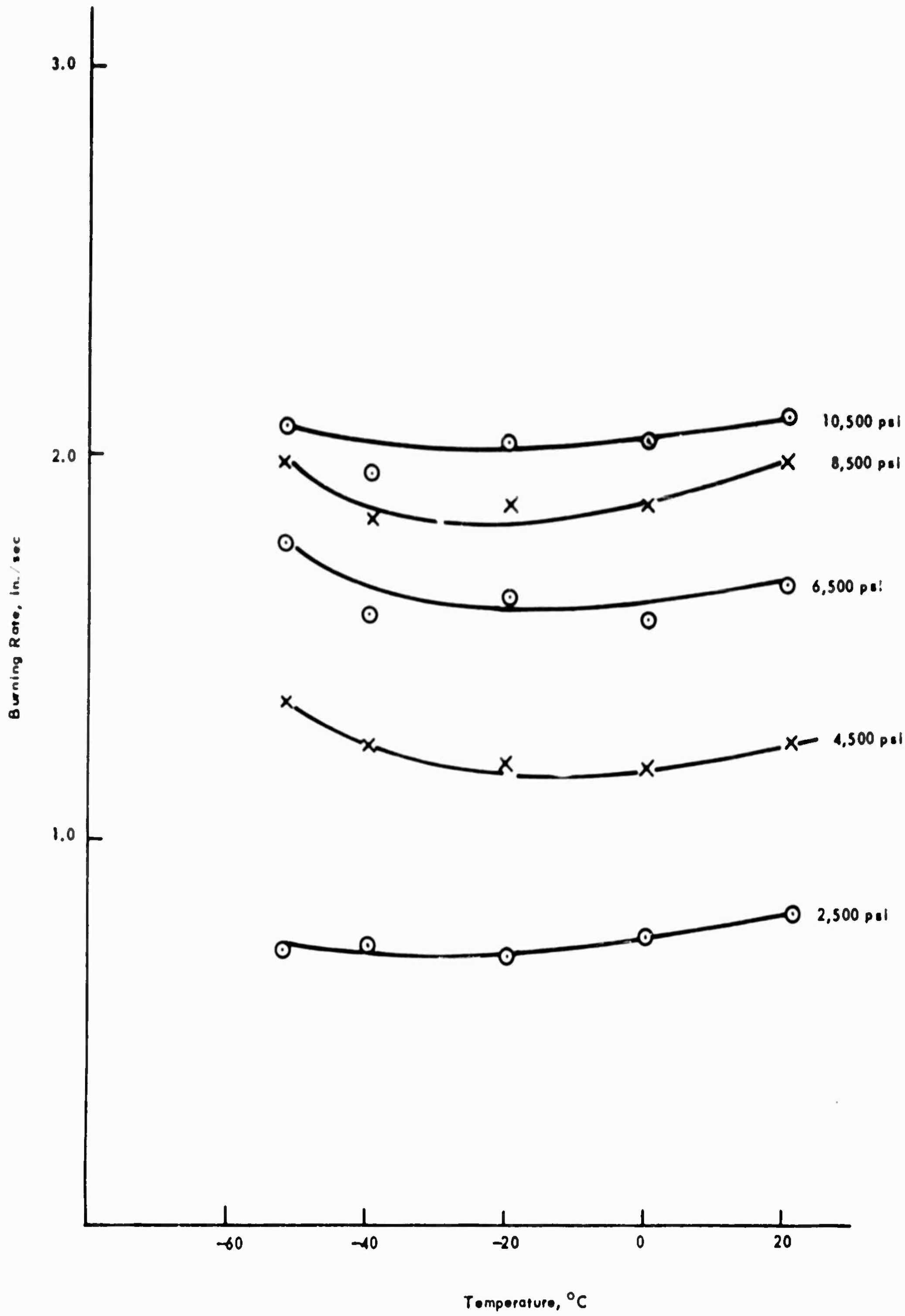

Fig 35 Burning rate vs temperature. M-10 propellant, PAE-30257

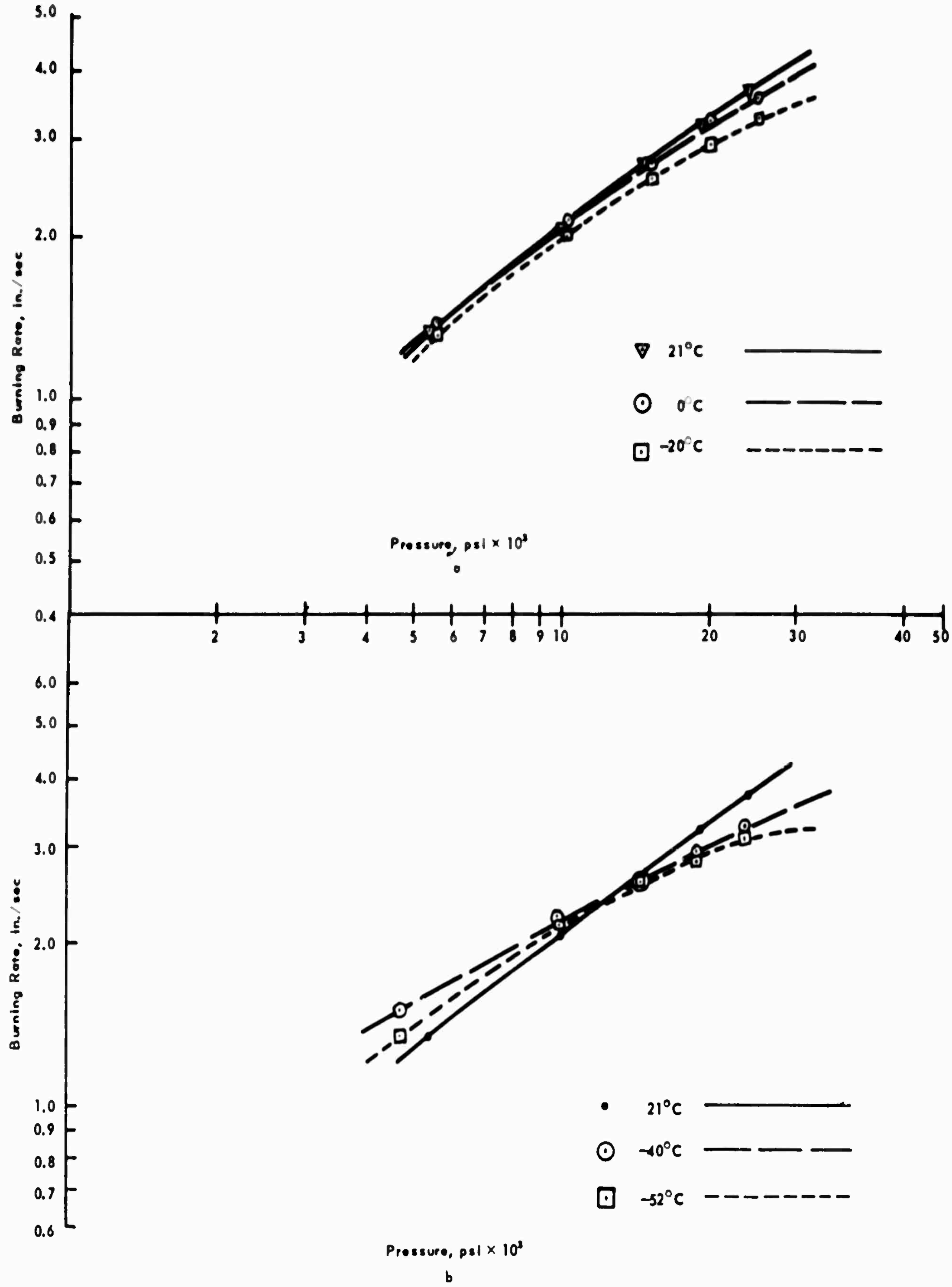

Fig 36   Burning rate vs pressure. M-15 propellant, RAD-38422. 0.2Δ

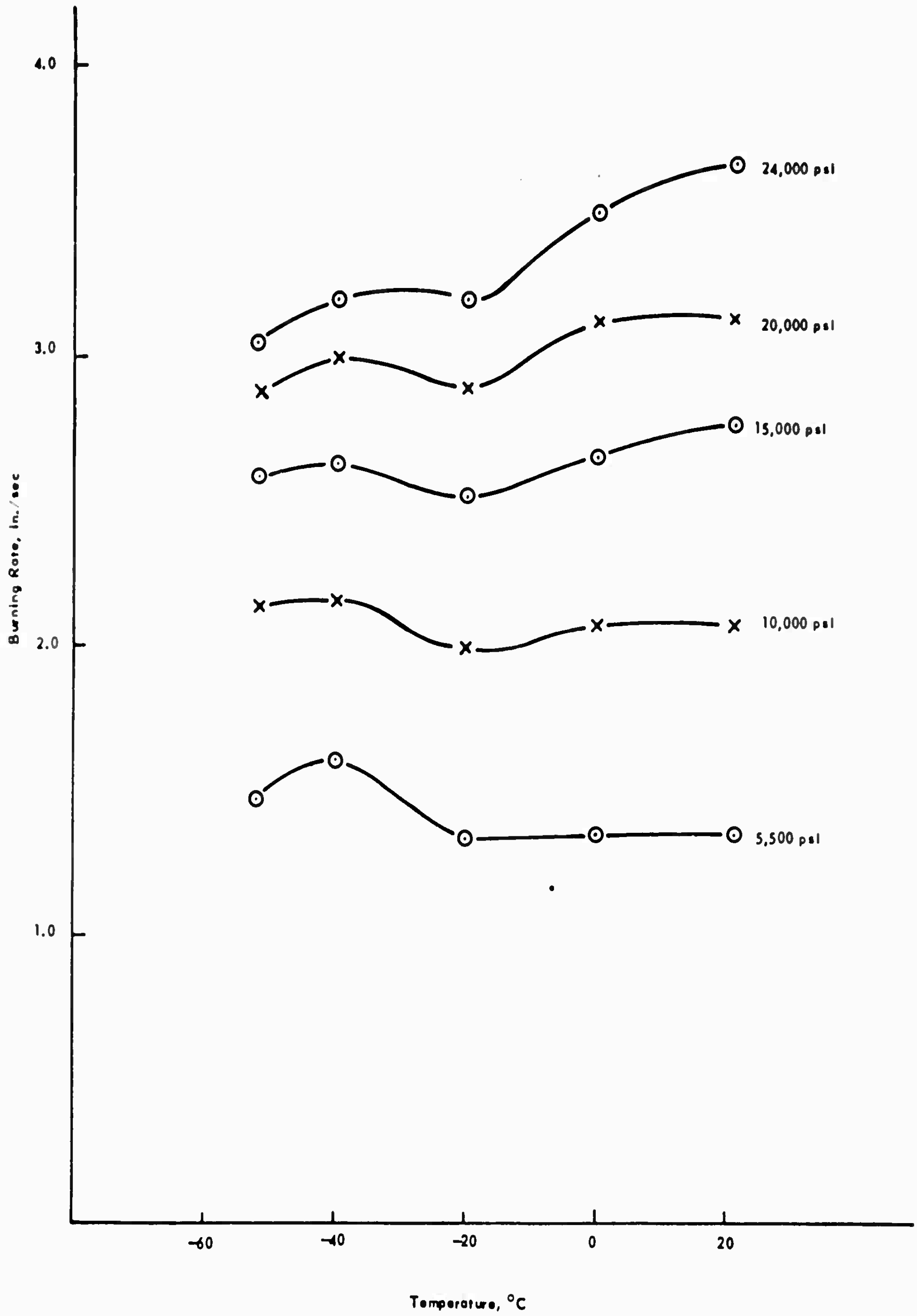

Fig 37 Burning rate vs temperature. M-15 propellant, RAD-38422

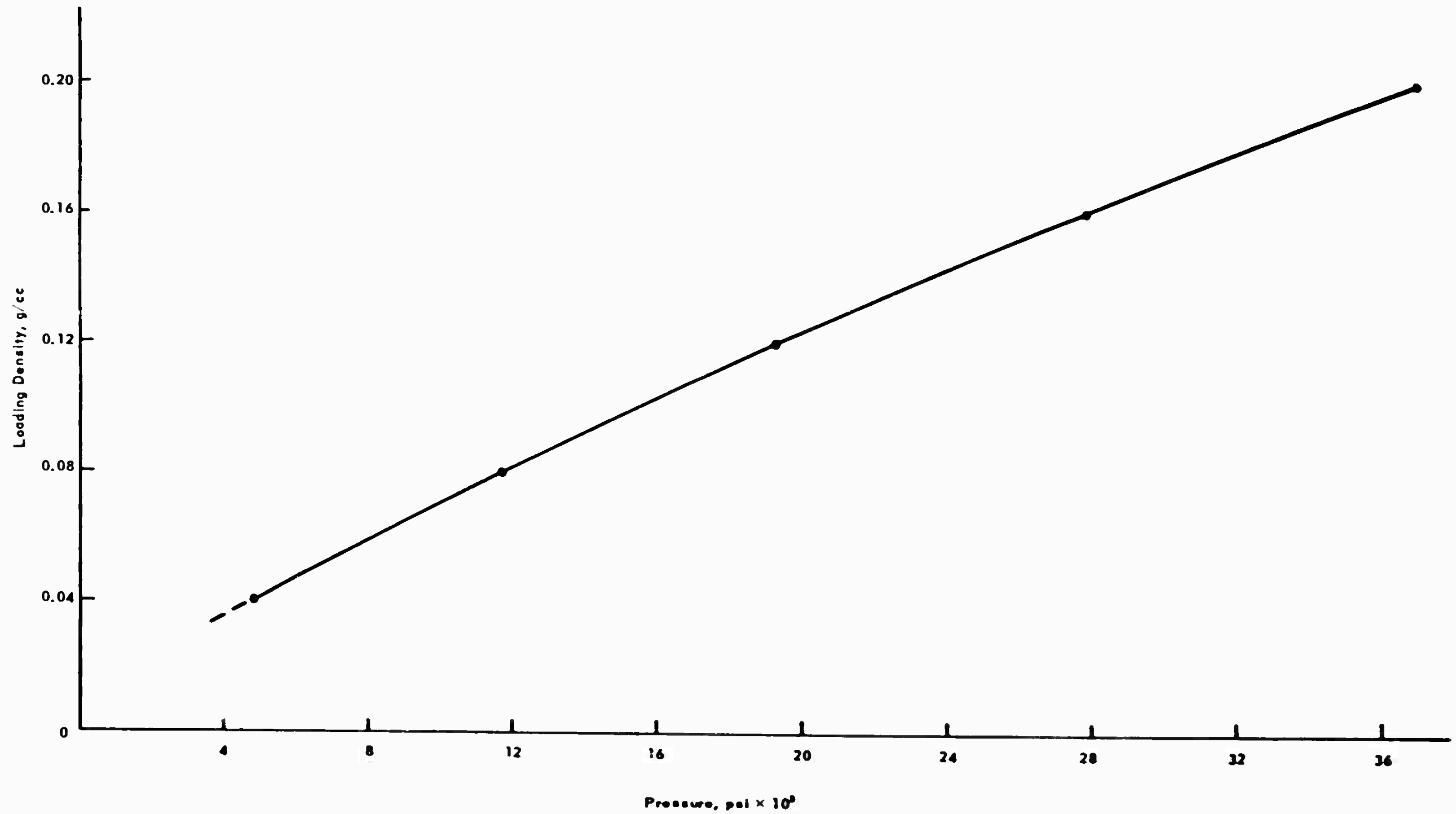

Fig 38 Loading density vs pressure. M-15 propellant, RAD-38422

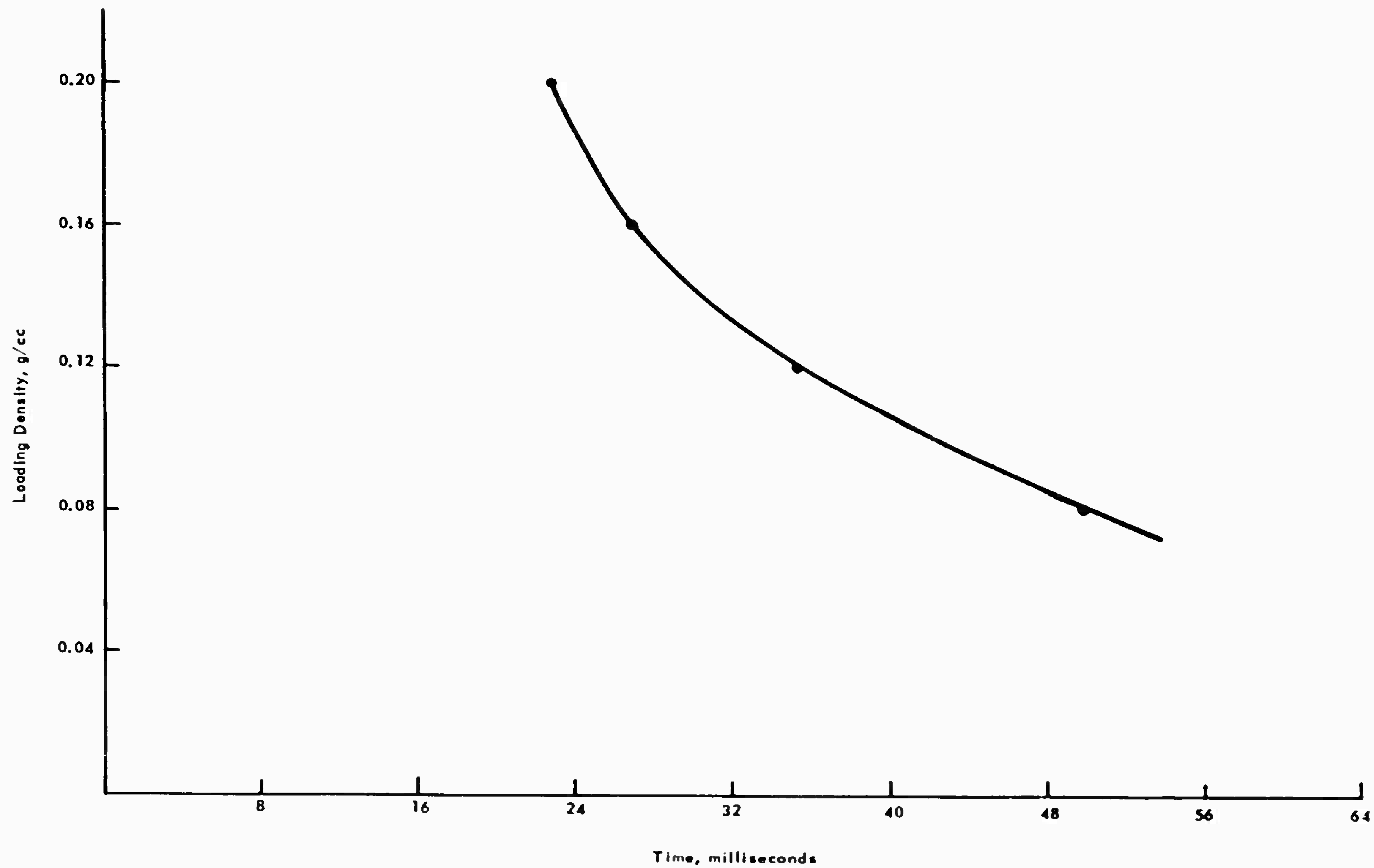

Fig 39 Loading density vs time of burning, M-15 propellant, RAD-38422

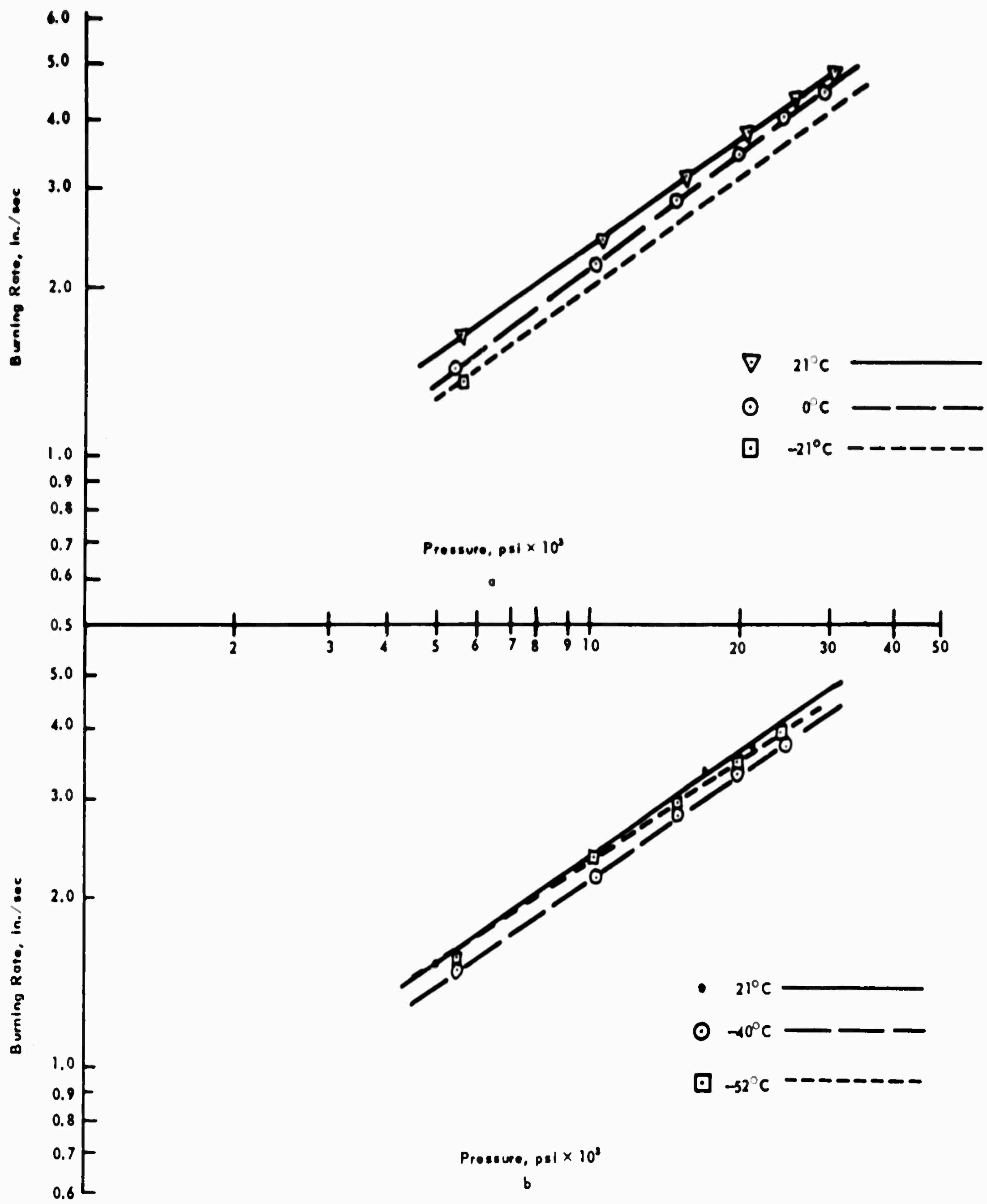

Fig 40 Burning rate vs pressure. M-17 propellant, RAD-38714. 0.2Δ

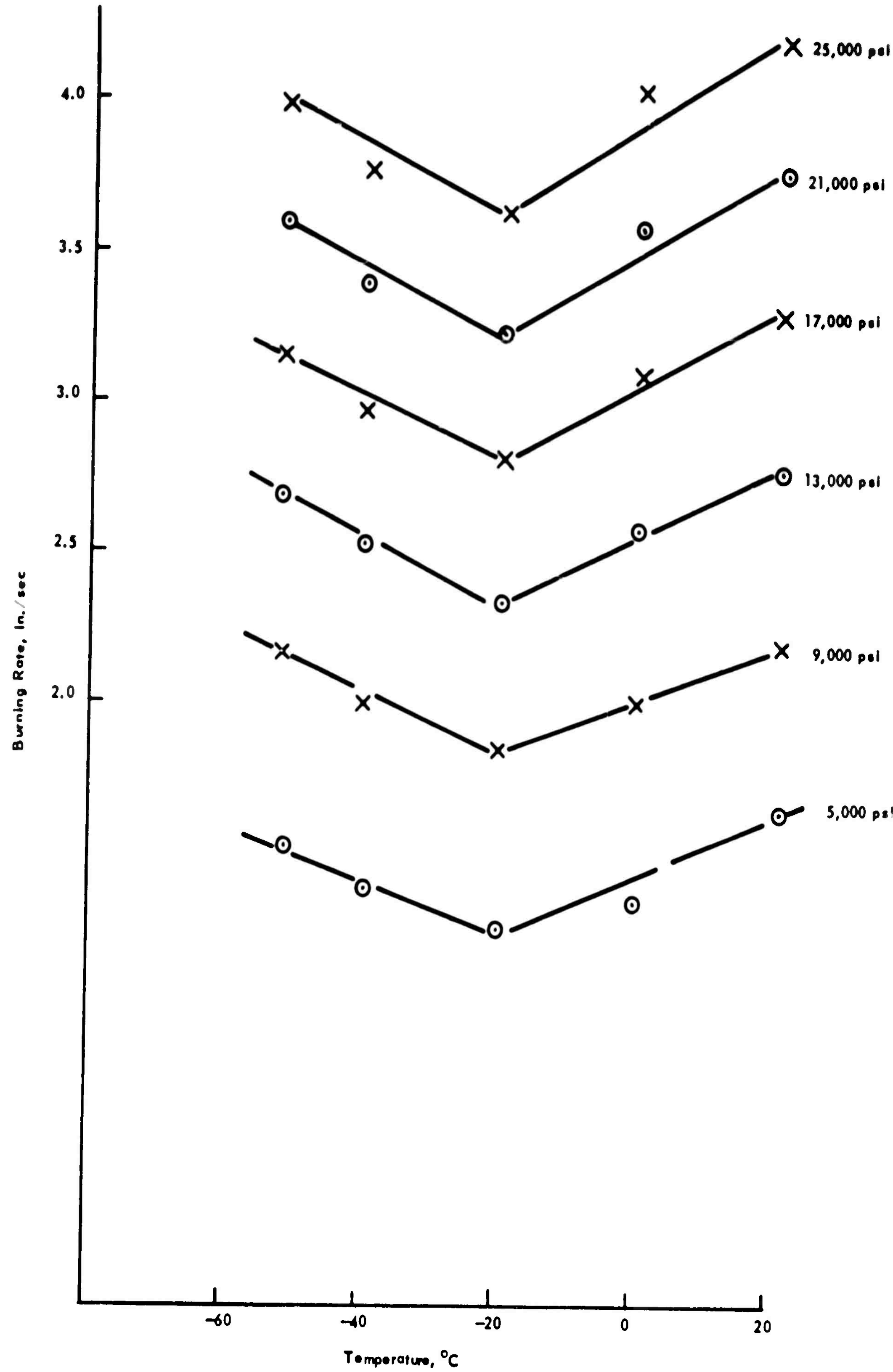

Fig 41 Burning rate vs temperature. M-17 propellant, RAD-38714

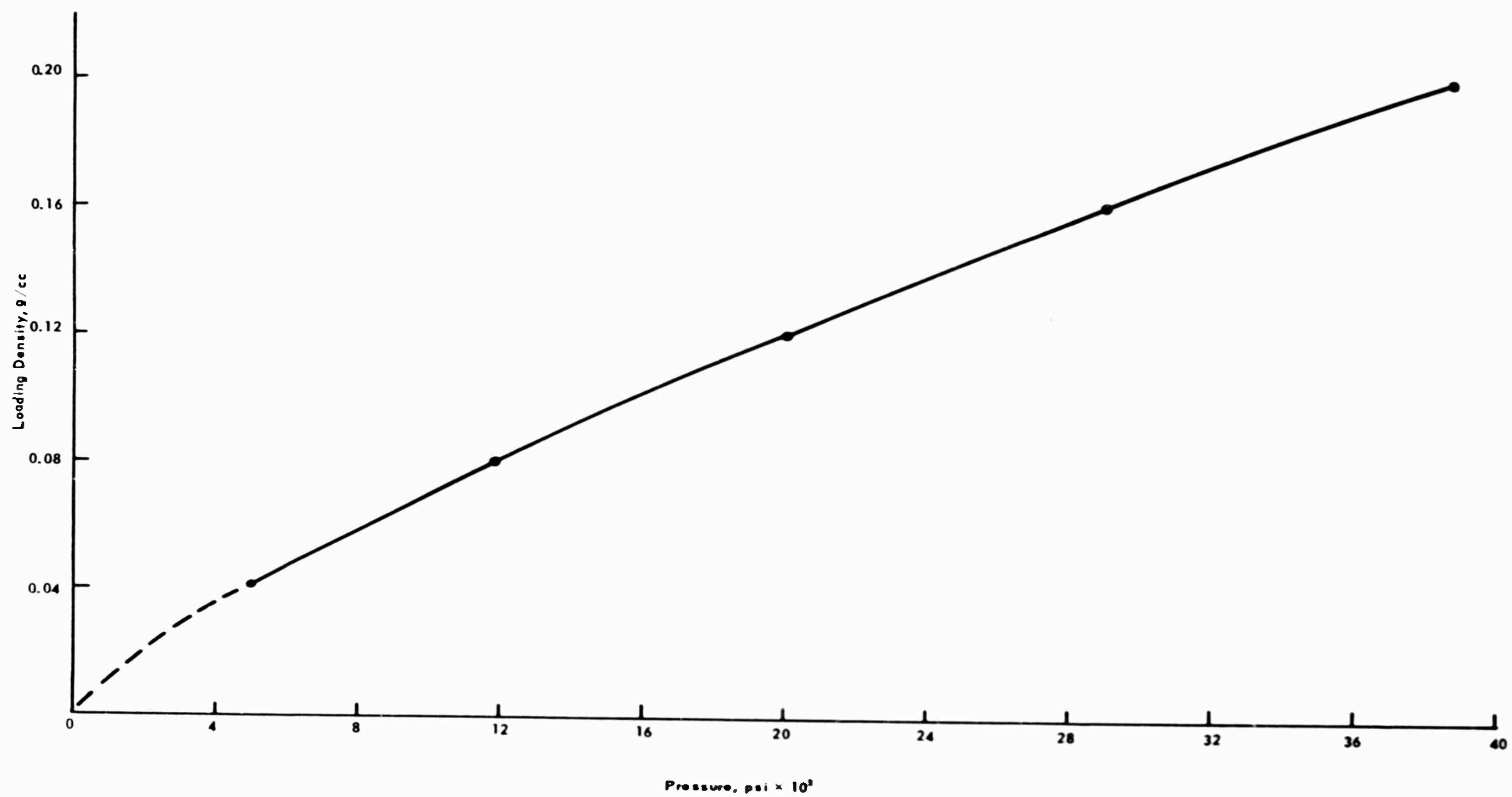

Fig 42 Loading density vs pressure. M-17 propellant, RAD-38714

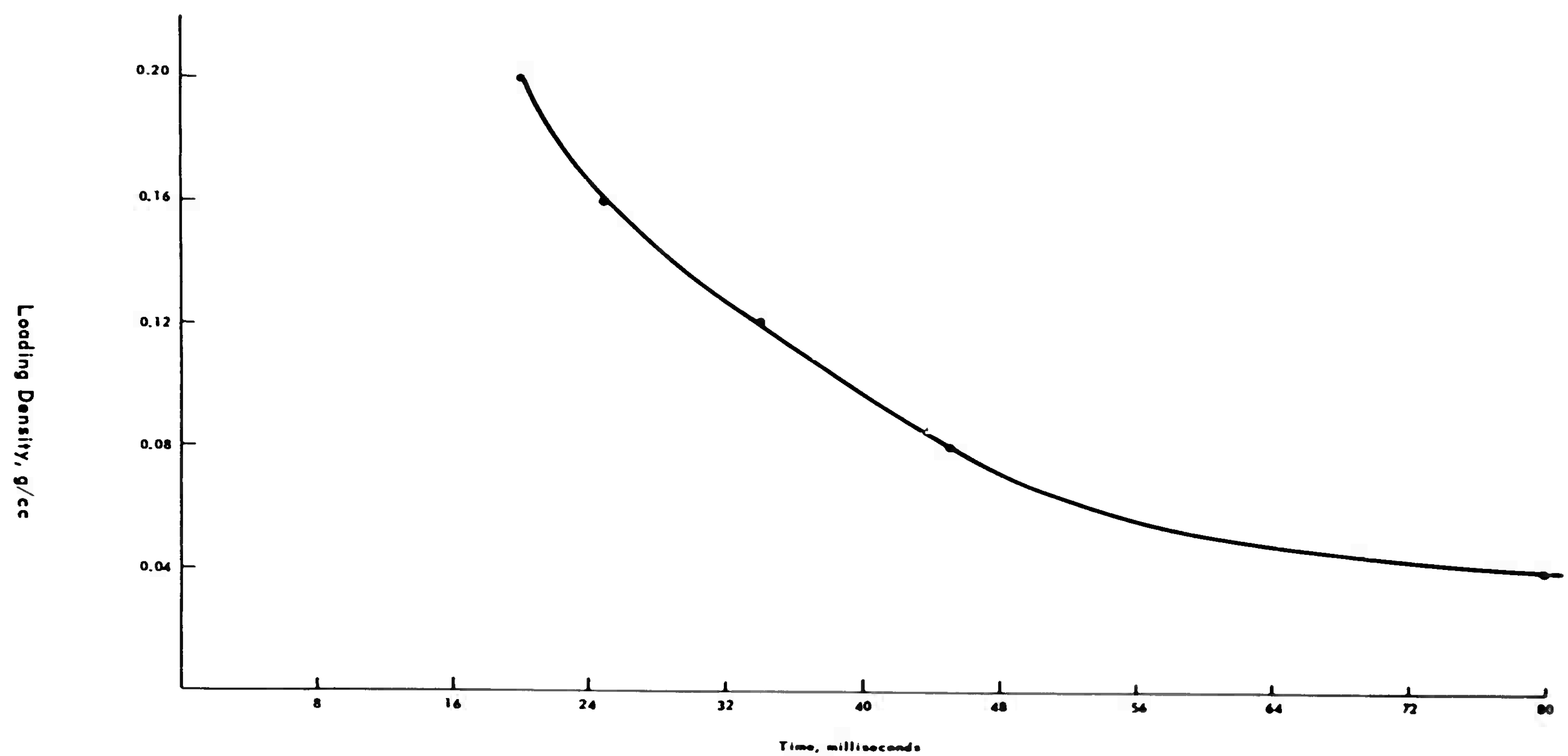

Fig 43 Loading density vs time of burning. M-17 propellant, RAD-38714

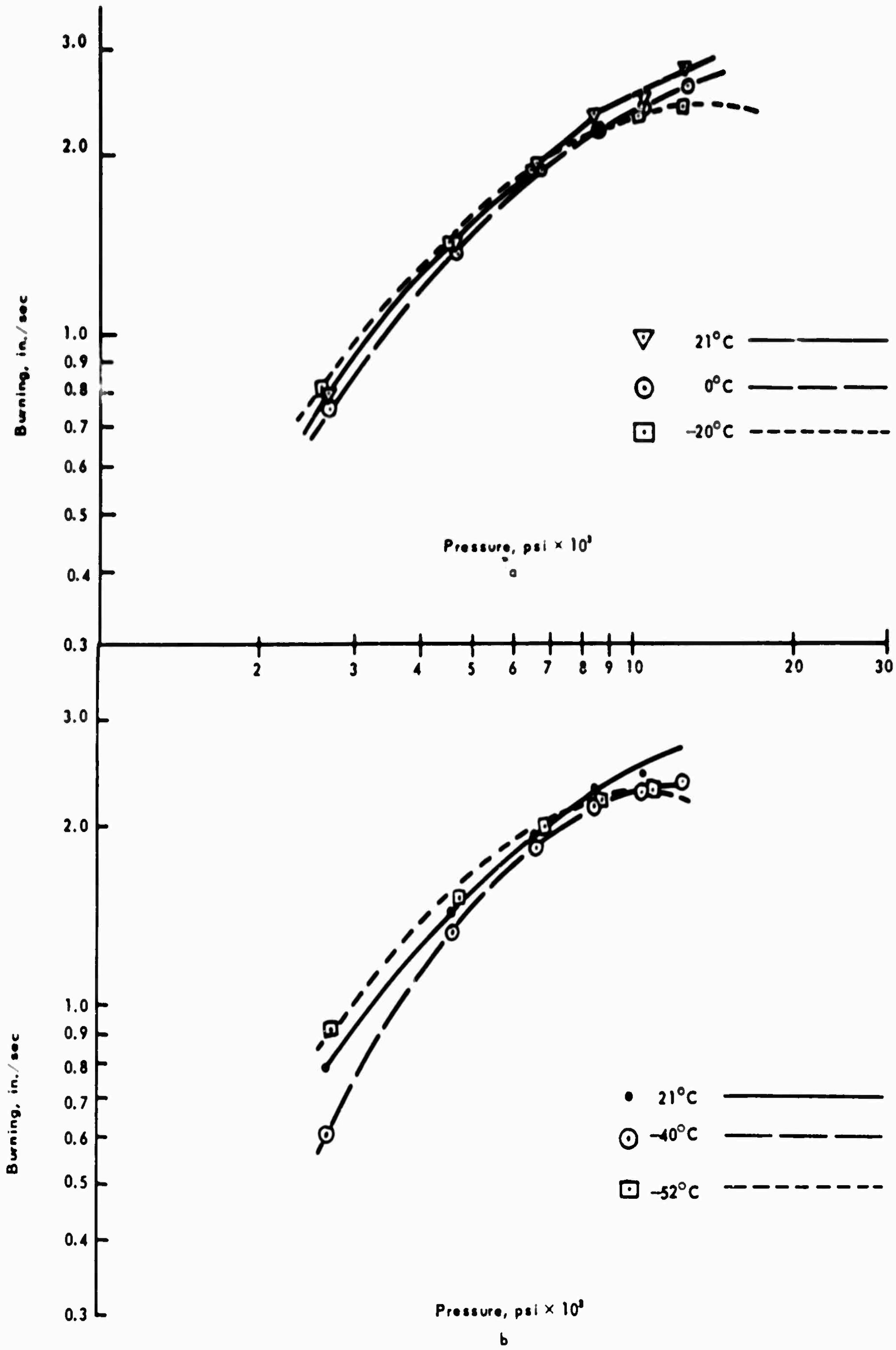

Fig 44 Burning rate vs pressure. T-28 propellant, RAD-60470. 0.1Δ

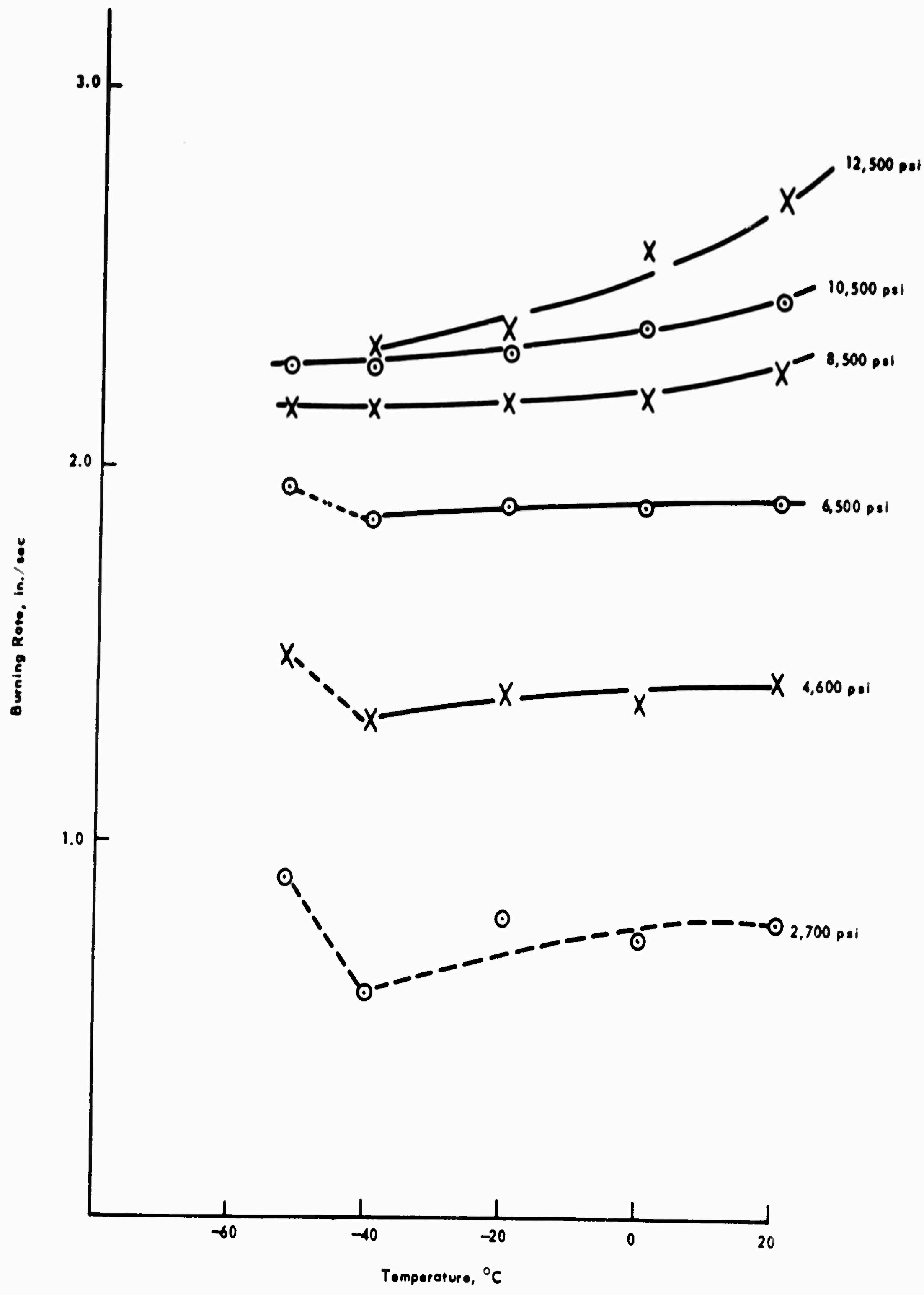

Fig 45 Burning rate vs temperature. T-28 propellant, RAD-60470

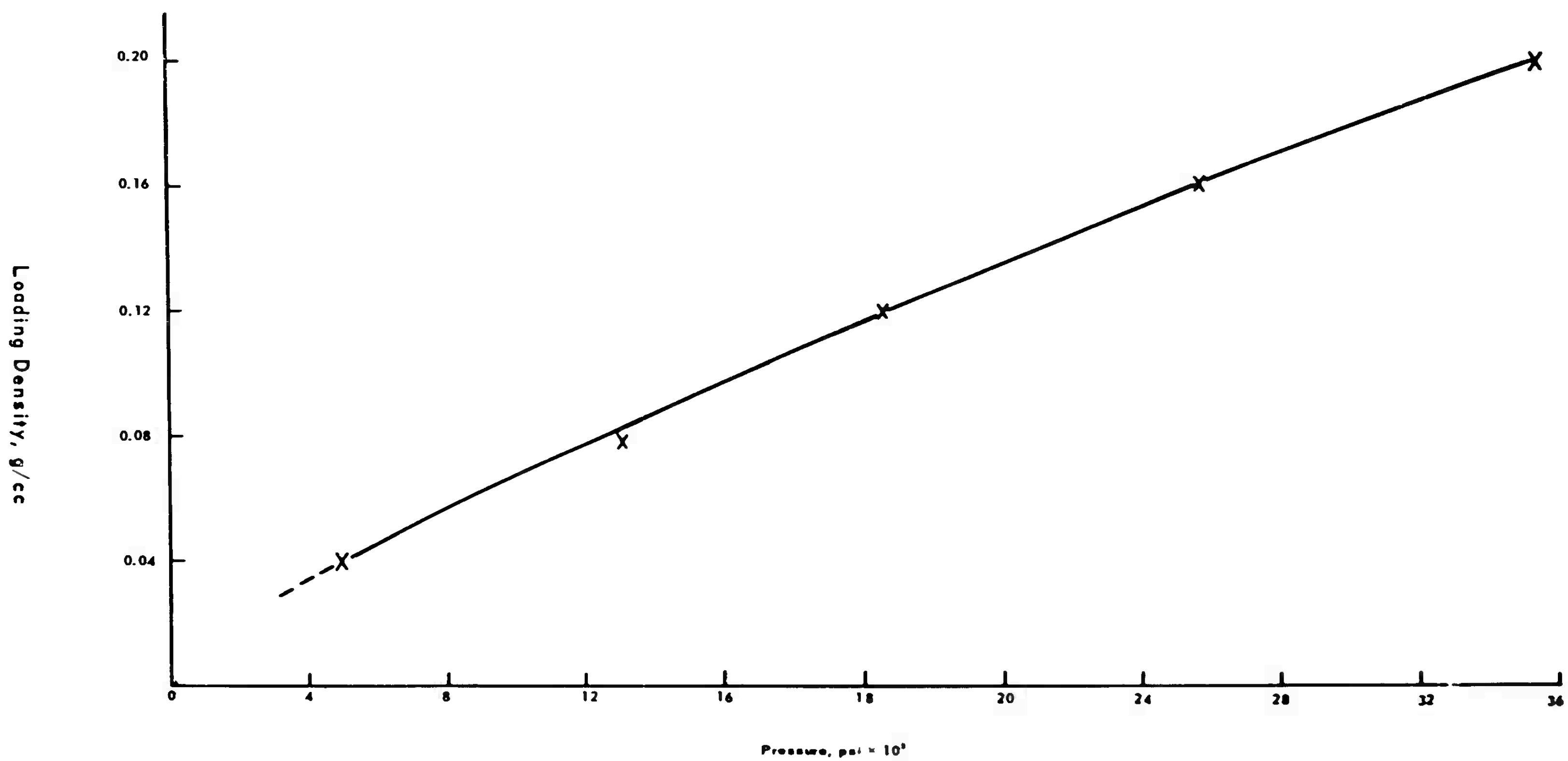

Fig 46 Loading density vs pressure. T-28 propellant, RAD-60470

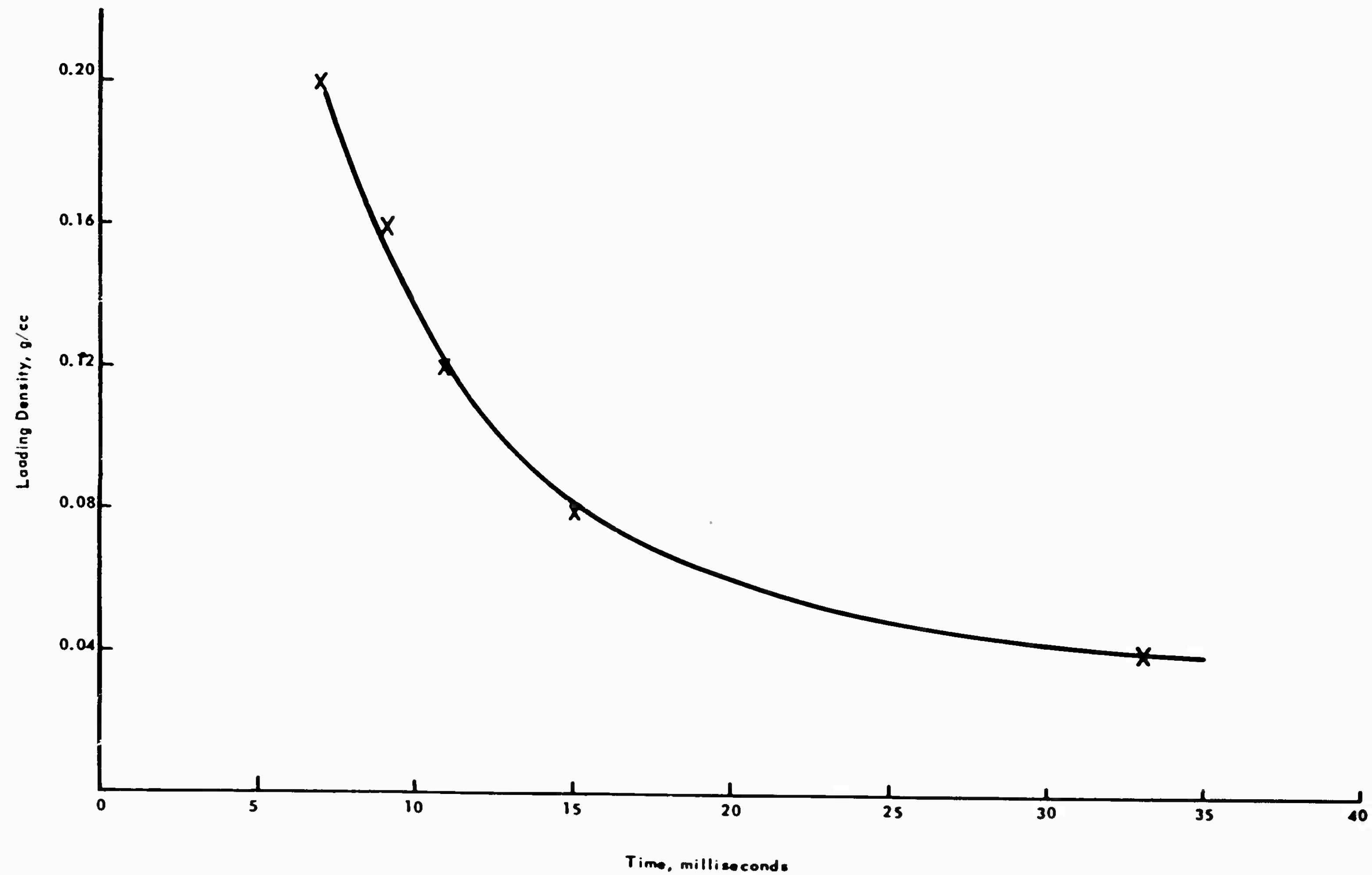

Fig 47   Loading density vs time of burning. T-28 propellant, RAD-60470

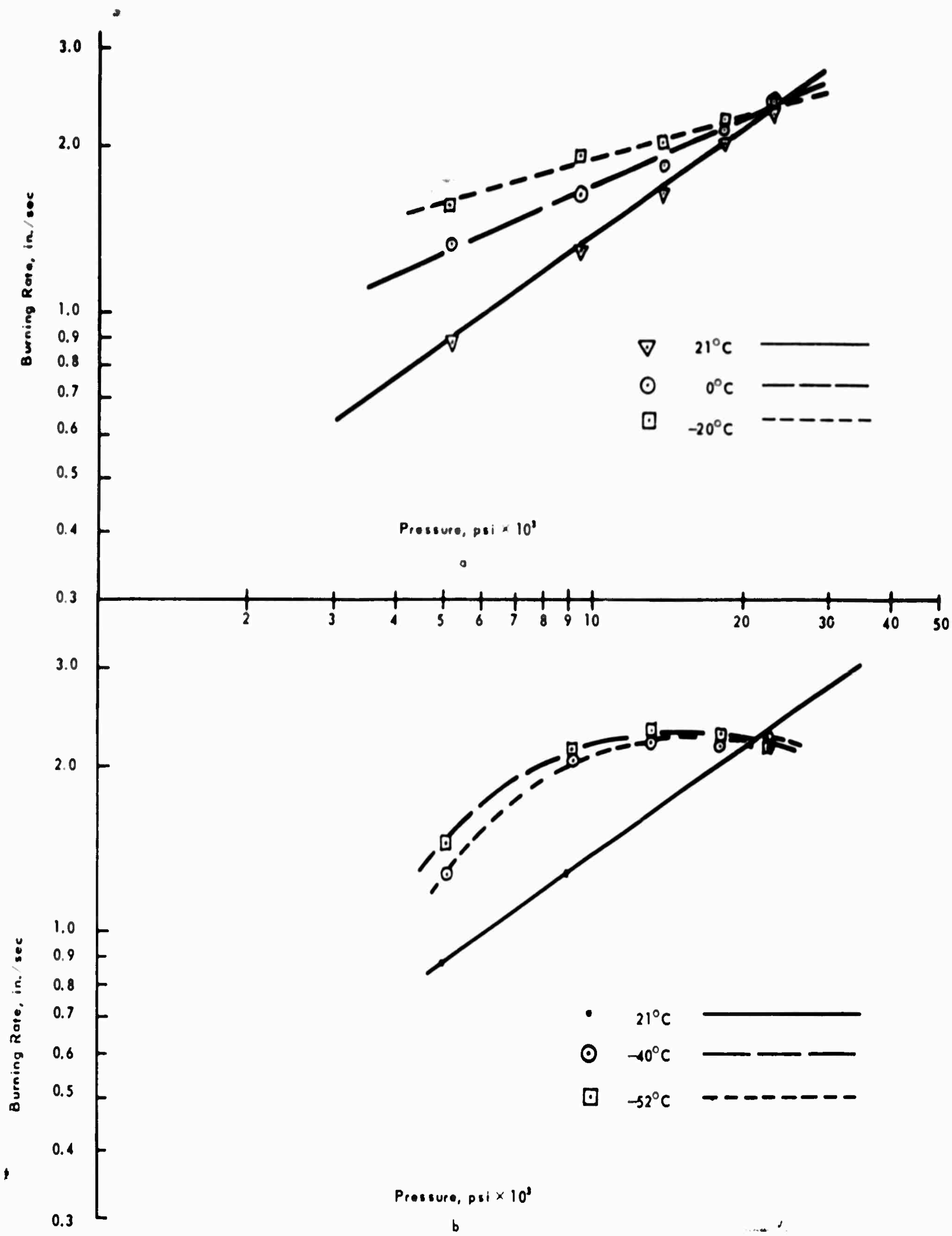

Fig 48 Burning rate vs pressure. T-34 propellant, PAE-25333. 0.2Δ

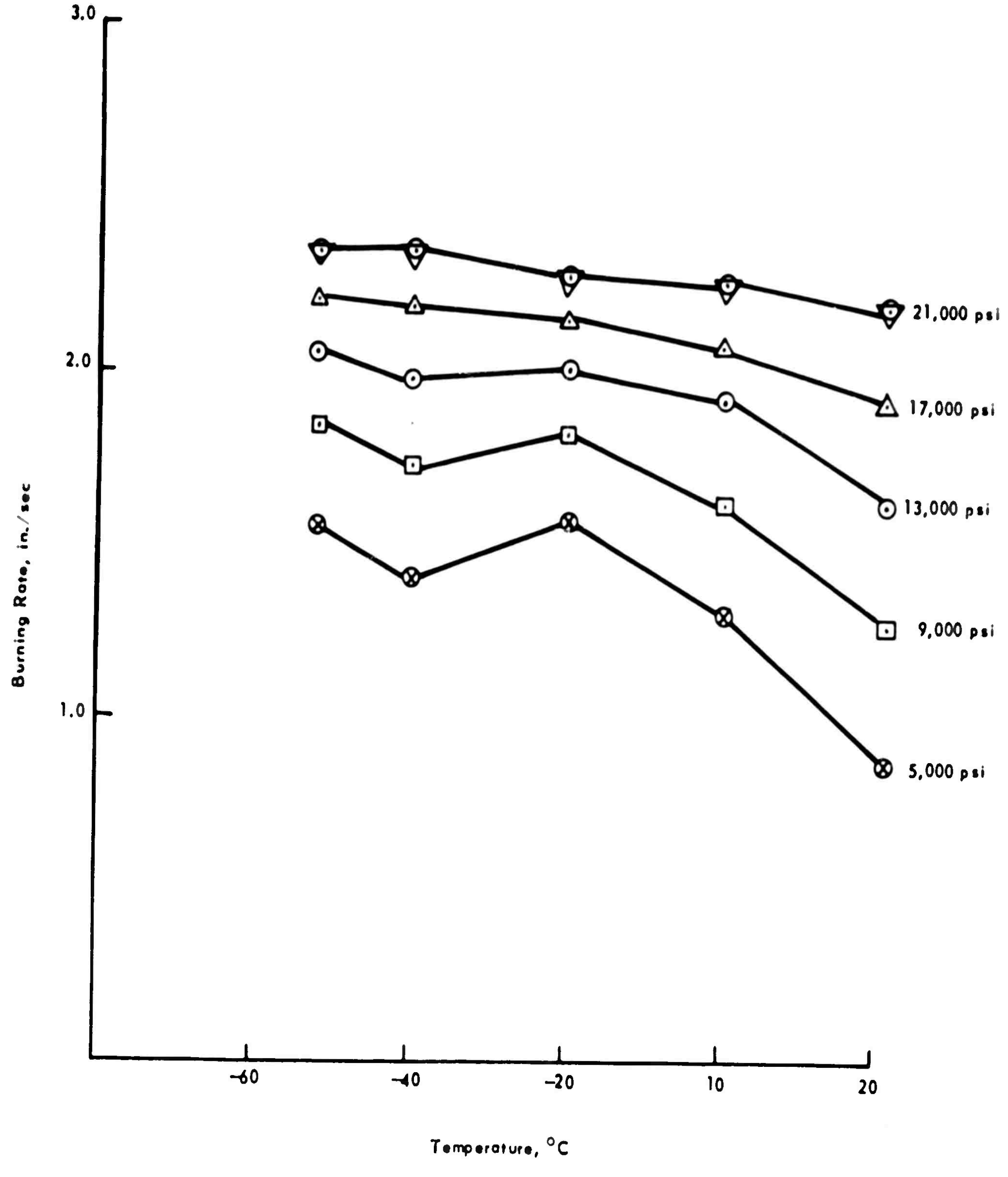

Fig 49 Burning rate vs temperature. T-34 propellant, PAE-25333

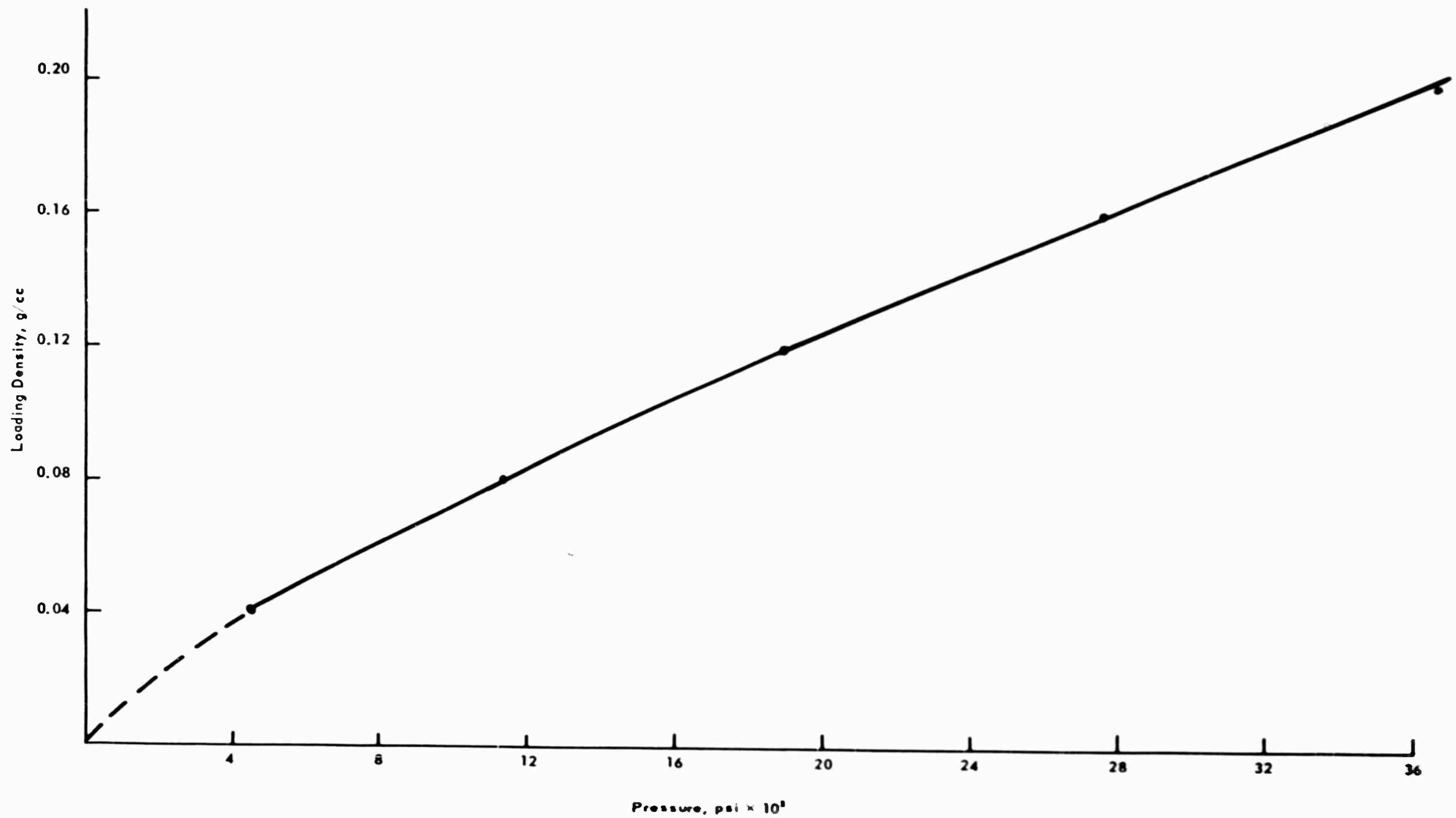

Fig 50   Loading density vs pressure. T-34 propellant, PAE-25333

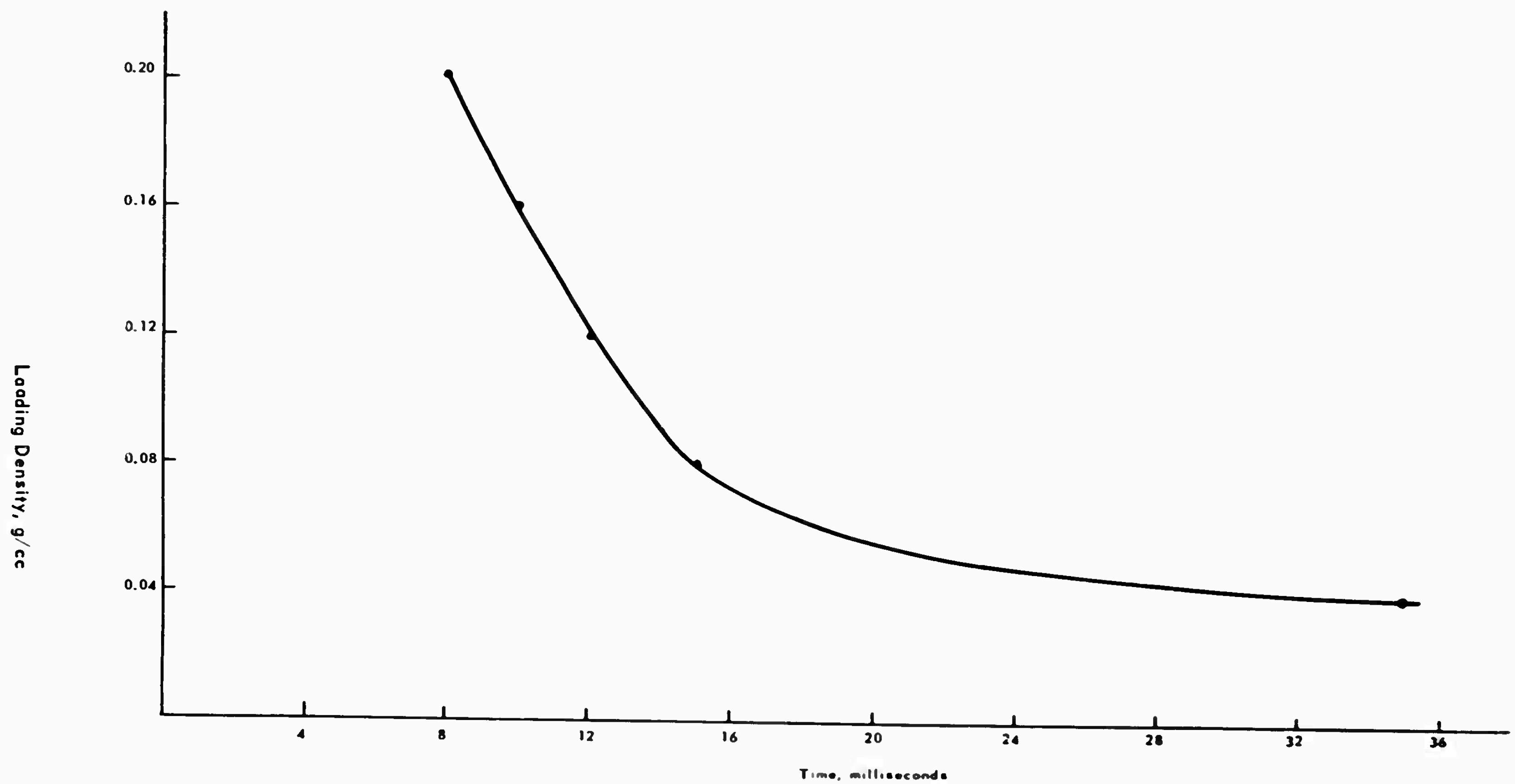

Fig 51 Loading density vs time of burning. T-34 propellant, PAE-25333

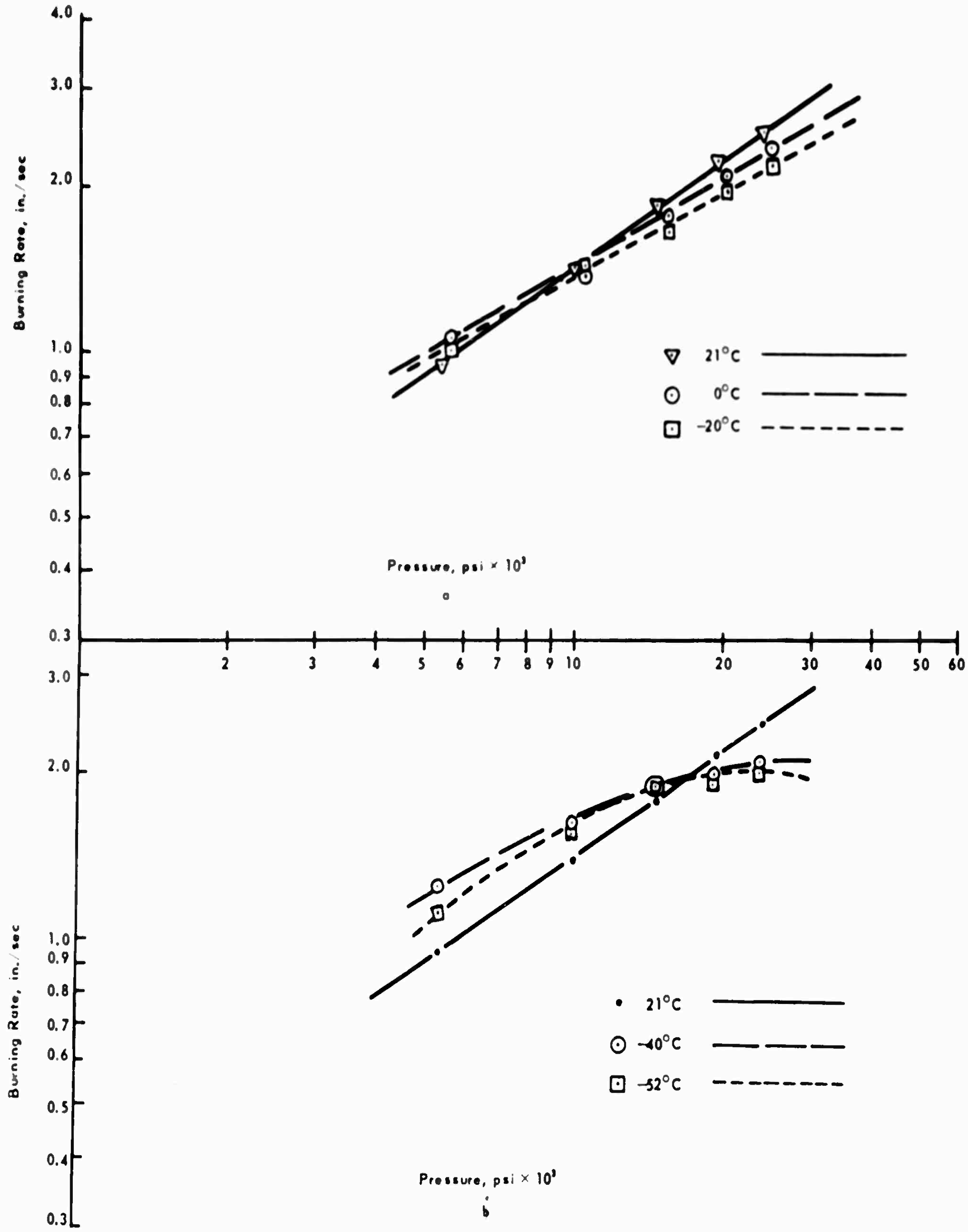

Fig 52 Burning rate vs pressure. T-34 propellant, SUN-IS-604. 0.2Δ

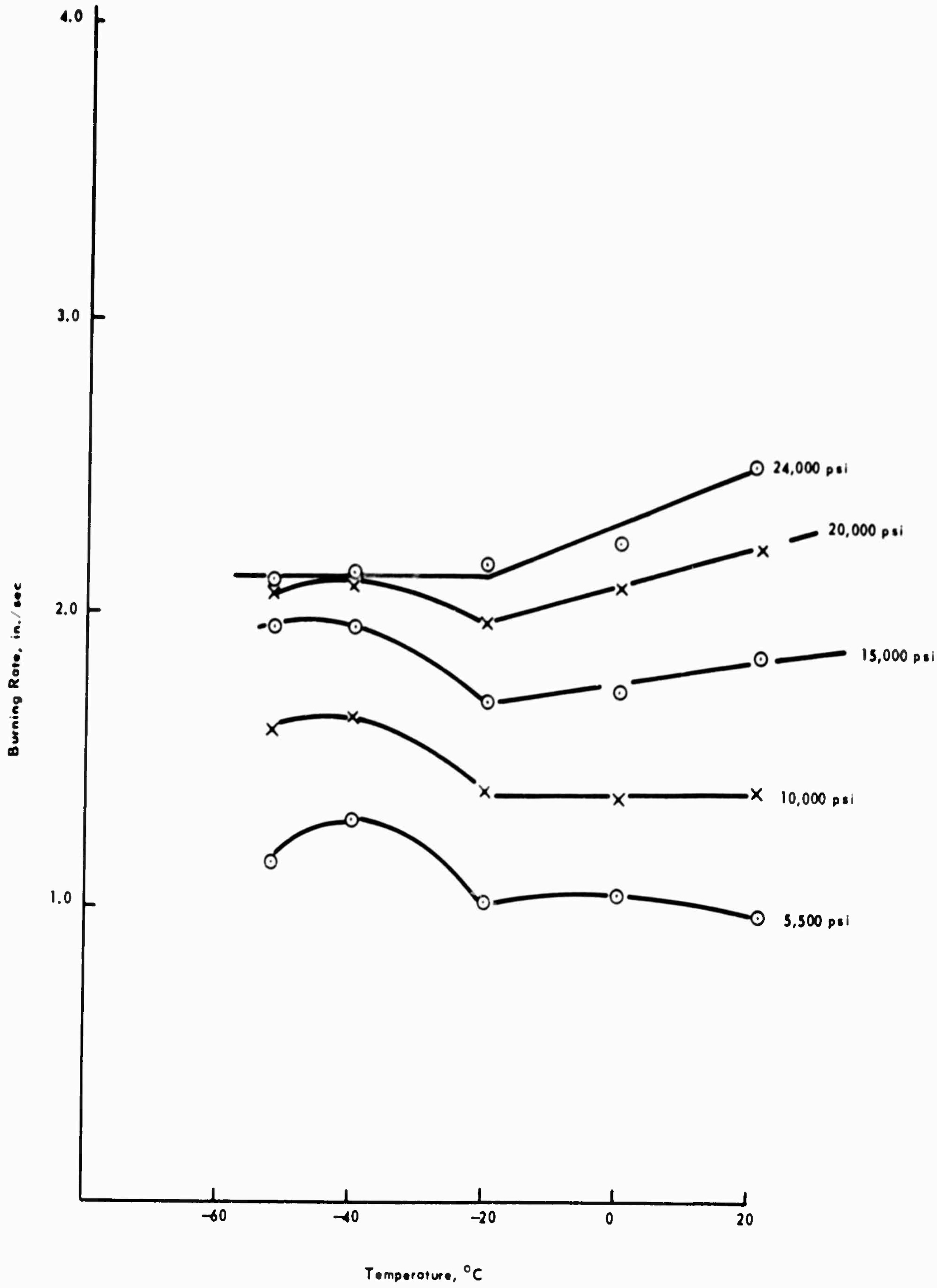

Fig 53 Burning rate vs temperature. T-34 propellant, SUN-IS-604

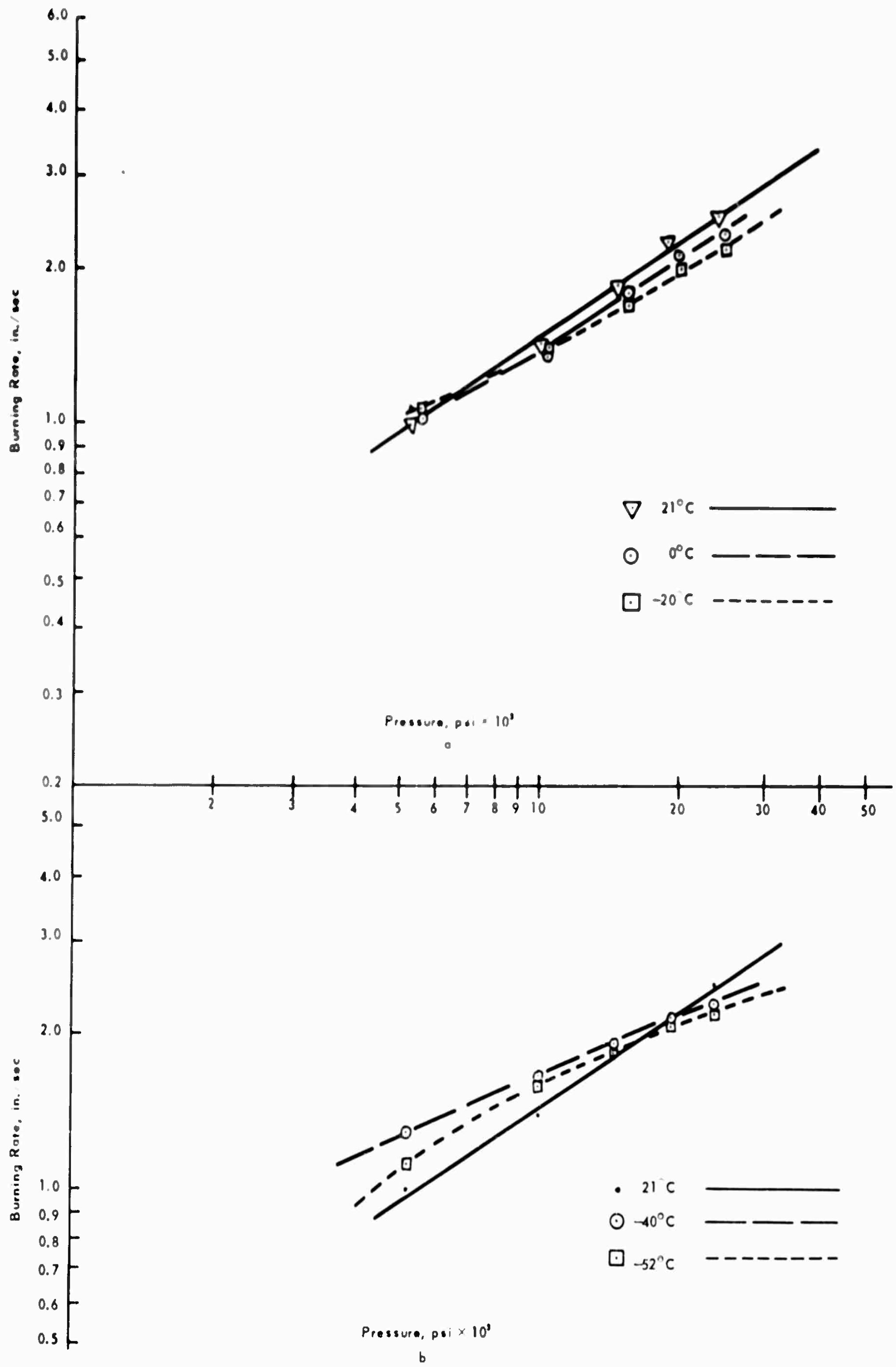

Fig 54 Burning rate vs pressure. T-34 propellant, SUN-IS-607. 0.2Δ

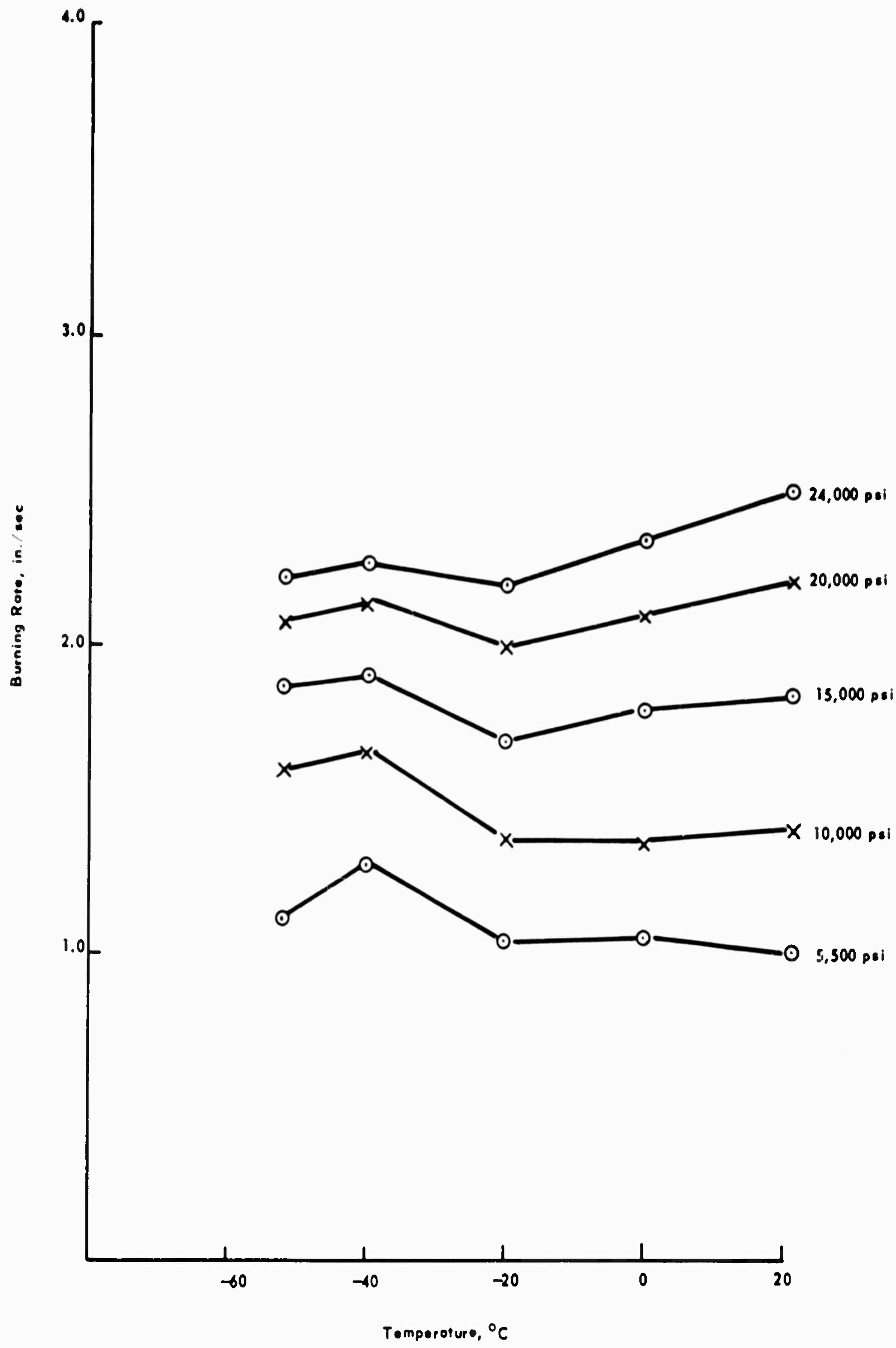

Fig 55 Burning rate vs temperature. T-34 propellant, SUN-IS-607

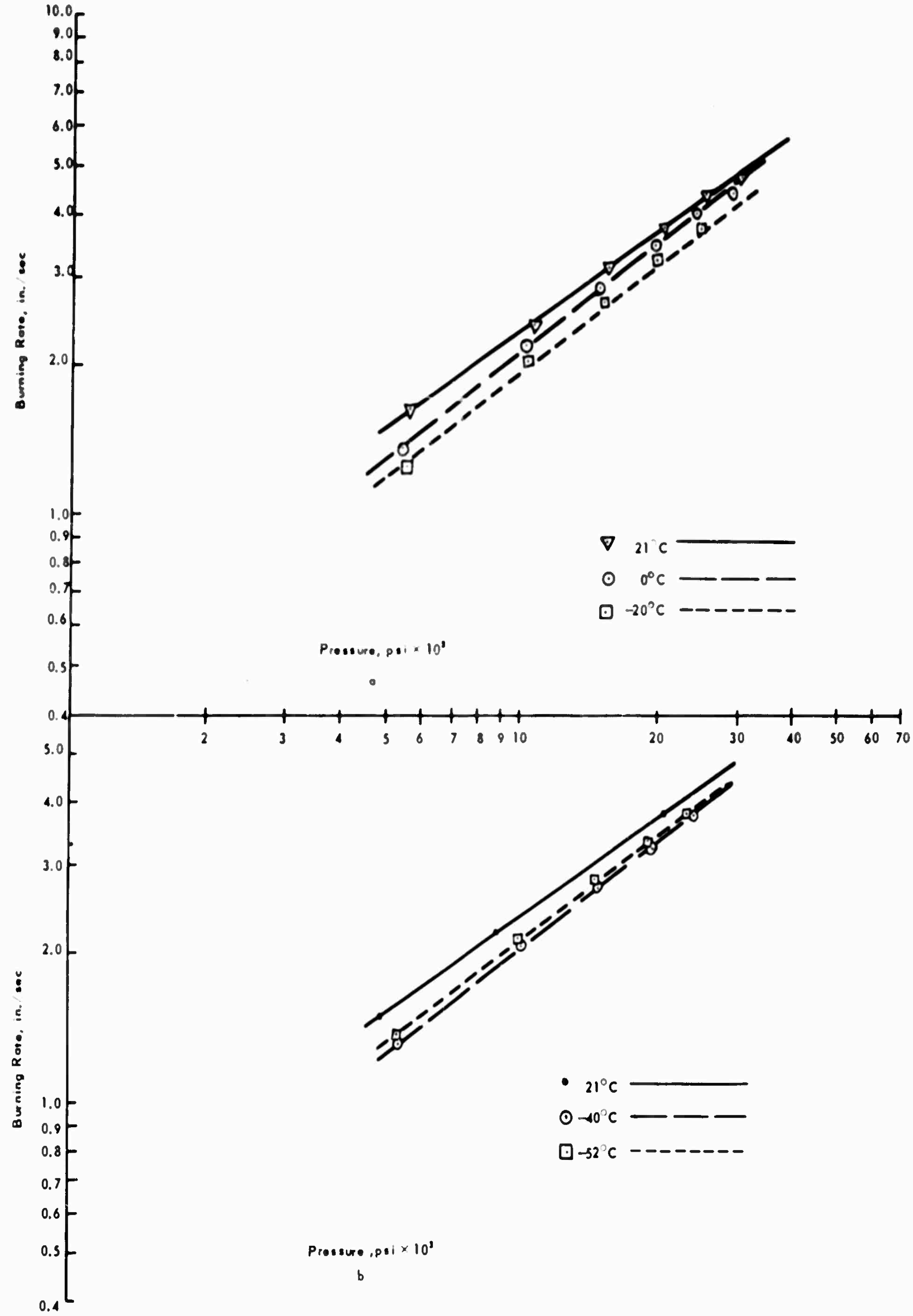

Fig 56 Burning rate vs pressure. T-36 propellant, EXP-5008C. 0.2Δ

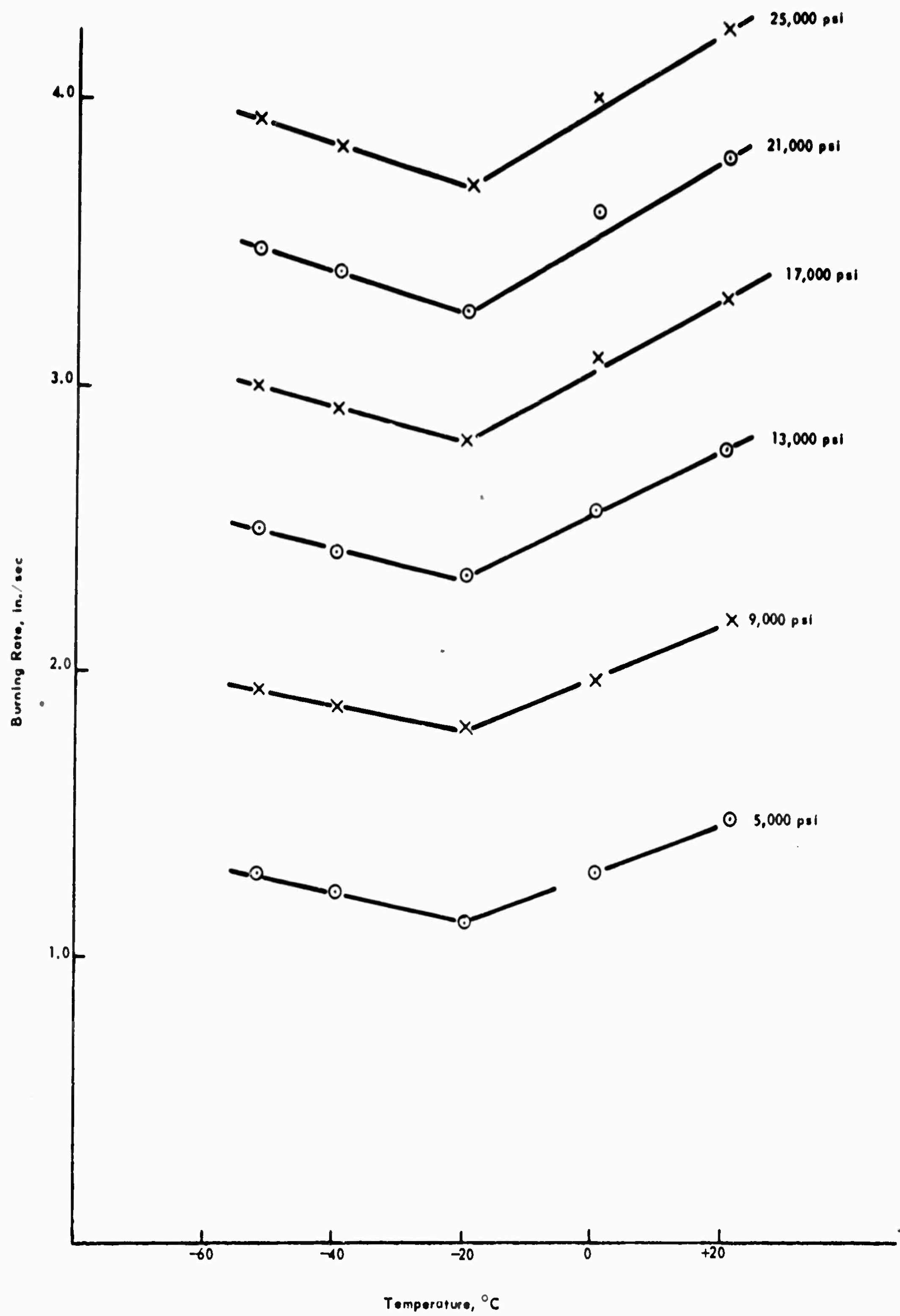

Fig 57 Burning rate vs temperature. T-36 propellant, 5008C

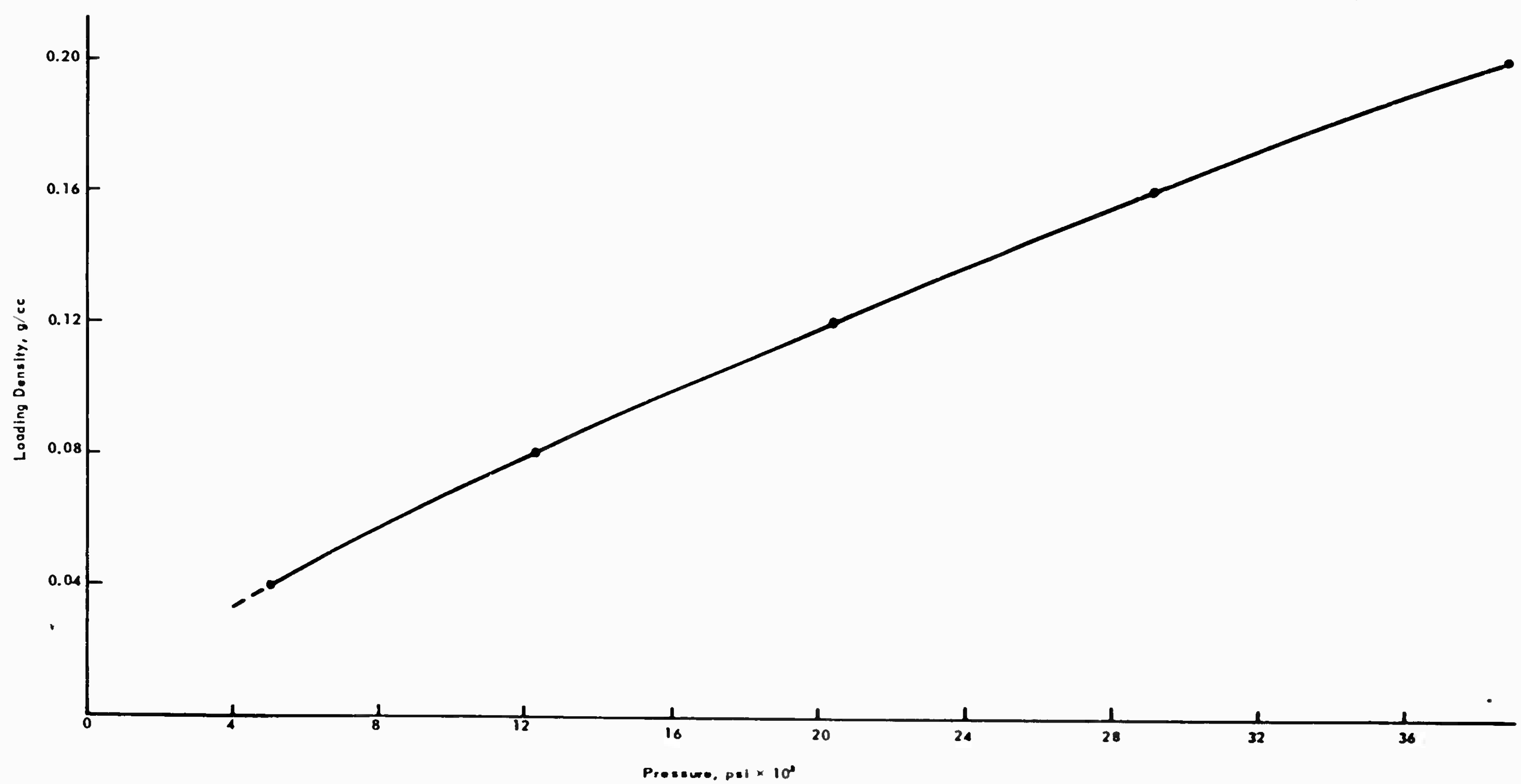

Fig 58 Loading density vs pressure. T-36 propellant, EXP-5008C

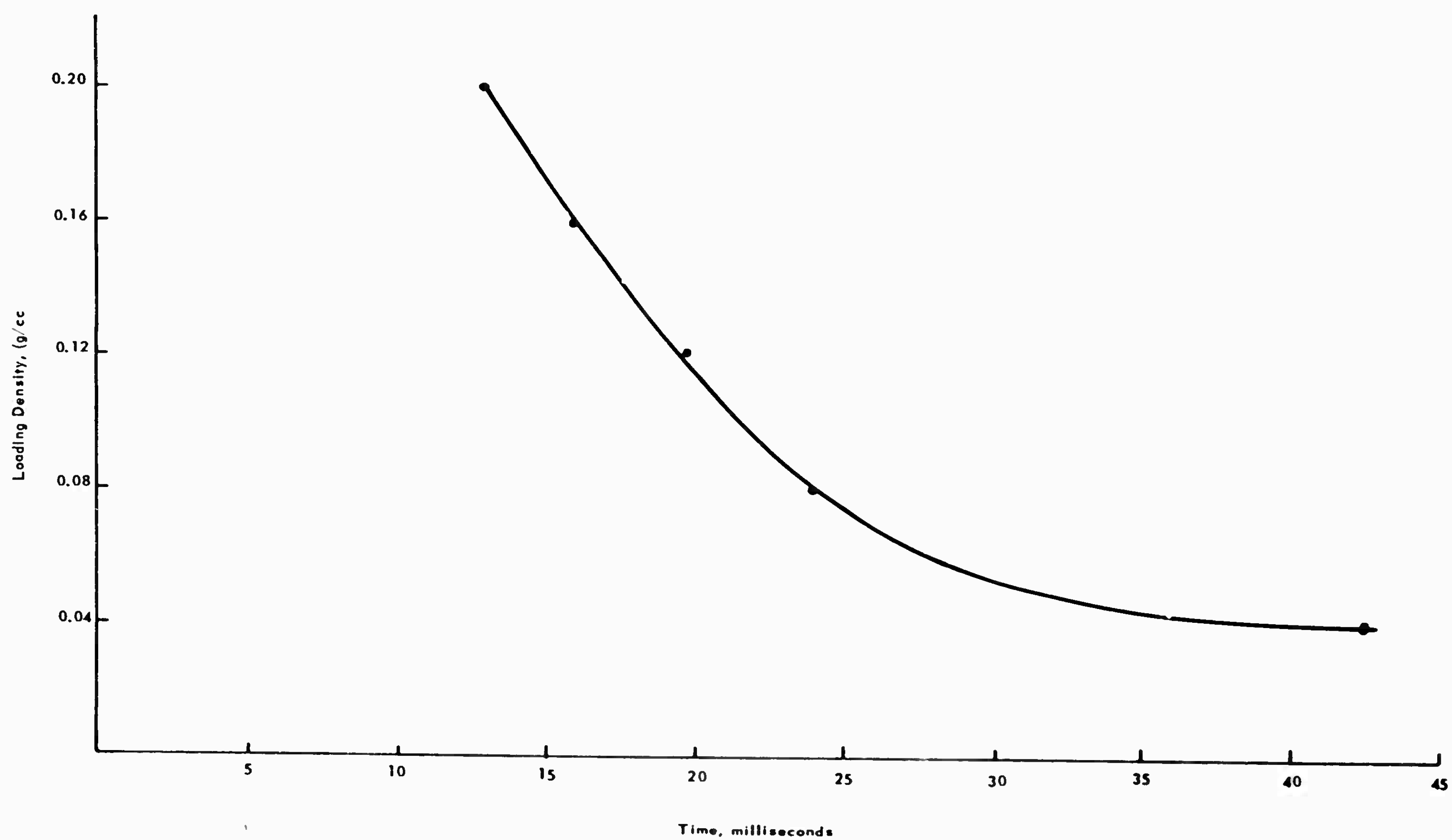

Fig 59 Loading density vs time of burning. T-36 propellant, EXP-5008C

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Picatinny Arsenal, Dover, N. J.

BURNING CHARACTERISTICS OF STANDARD GUN PROPELLANTS AT LOW TEMPERATURES (21°C TO −52°C)

Lester Shulman, Joel Harris, Charles Lenchitz

Technical Report FRL-TR-41, November 1961, 101 pp, tables, figures. DA Proj None, Ord Proj WDOAC-4700-142-19-99105 Item D-2-11. Unclassified Report

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III. Lenchitz, Charles
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